DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Mercury Control Systems

Final Site Report for:
Brayton Point Generating Station Unit 1
Sorbent Injection into a Cold-Side ESP for Mercury Control

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EXECUTIVE SUMMARY

Brayton Point Unit 1 was successfully tested for applicability of activated carbon injection as a mercury control technology. Test results from this site have enabled a thorough evaluation of the impacts of future mercury regulations to Brayton Point Unit 1, including performance, estimated cost, and operation data. This unit has variable (29–75%) native mercury removal, thus it was important to understand the impacts of process variables and activated carbon on mercury capture.

The team responsible for executing this program included:

- Plant and PG&E National Energy Group corporate personnel
- Electric Power Research Institute (EPRI)
- United States Department of Energy National Energy Technology Laboratory (DOE/NETL)
- ADA-ES, Inc.
- NORIT Americas, Inc.
- Apogee Scientific, Inc.
- TRC Environmental Corporation
- URS Corporation
- Quinapoxet Solutions
- Energy and Environmental Strategies (EES)
- Reaction Engineering International (REI)

The technical support of all of these entities came together to make this program achieve its goals.

Overall, the objectives of this field test program were to determine the impact of activated carbon injection on mercury control and balance-of-plant processes on Brayton Point Unit 1. Brayton Point Unit 1 is a 250-MW unit that fires a low-sulfur eastern bituminous coal. Particulate control is achieved by two electrostatic precipitators (ESPs) in series. The full-scale tests were conducted on one-half of the flue gas stream (nominally 125 MW). Mercury control sorbents were injected in between the two ESPs. The residence time from the injection grid to the second ESP was approximately 0.5 seconds.

In preparation for the full-scale tests, 12 different sorbents were evaluated in a slipstream of flue gas via a packed-bed field test apparatus for mercury adsorption. Results from these tests were used to determine the five carbon-based sorbents that were tested at full-scale. Conditions of interest that were varied included SO_3 conditioning on/off, injection concentrations, and distribution spray patterns.

The original test plan called for parametric testing of NORIT FGD carbon at 1, 3, and 10 lbs/MMacf. These injection concentrations were estimated based on results from the Pleasant Prairie tests that showed no additional mercury removal when injection concentrations were increased above 10 lbs/MMacf. The Brayton Point parametric test data indicated that higher injection concentrations would achieve higher removal efficiencies and should be tested. The test plan was altered to include testing at 20 lbs/MMacf. The first test at this higher rate showed very high removal across the second ESP (>80%). Unlike the "ceiling" phenomenon witnessed at Pleasant Prairie, increasing sorbent injection concentration resulted in further capture of vapor-phase mercury.

The final phase of field-testing was a 10-day period of continuous injection of NORIT FGD carbon. During the first five days, the injection concentration was held at 10 lbs/MMacf, followed by nominally five days of testing at an injection concentration of 20 lbs/MMacf. The mercury removal, as measured by the semi-continuous emission monitors (S-CEM), varied between 78% and 95% during the 10 lbs/MMacf period and increased to >97% when the injection concentration was increased to 20 lbs/MMacf.

During the long-term testing period, mercury measurements following EPA's draft Ontario Hydro method were conducted by TRC Environmental Corporation at both 10 and 20 lbs/MMacf test conditions. The Ontario Hydro data showed that the particulate mercury removal was similar between the two conditions of 10 or 20 lbs/MMacf and removal efficiencies were greater than 99%. Elemental mercury was not detected in any samples, so no conclusions as to its removal can be drawn. Removal of oxidized mercury, on the other hand, increased from 68% to 93% with the higher injection concentration. These removal rates agreed well with the S-CEM results.

INTRODUCTION

In December 2000, the U.S. Environmental Protection Agency (EPA) announced the intent to regulate mercury emissions from the nation's coal-fired power plants. In anticipation of this announcement, a great deal of research was conducted to characterize the emission and control of mercury compounds from the combustion of coal. Much of this research was funded by the Department of Energy (DOE), EPA, and Electric Power Research Institute (EPRI). The results are summarized in the comprehensive AWMA Critical Review article[1]. As a result of these efforts, the following was determined:

1. Trace concentrations of mercury in flue gas can be measured relatively accurately;
2. Mercury is emitted in a variety of forms;
3. Mercury species vary with fuel source and combustion conditions; and
4. Control of mercury from utility boilers will be both difficult and expensive.

This latter point was one of the most important and dramatic findings from the research. Because of the large volumes of gas to be treated, low concentrations of mercury, and presence of difficult-to-capture species such as elemental mercury, some estimates show that 90% mercury reduction for utilities could cost the industry as much as $5 billion per year[1]. Most of these costs will be borne by power plants that burn low-sulfur coal and do not have wet scrubbers as part of their air pollution equipment.

With regulations rapidly approaching, it was important to concentrate efforts on the most mature retrofit control technologies. Injection of dry sorbents such as powdered activated carbon (PAC) into the flue gas and further collection of the sorbent by electrostatic precipitators (ESPs) and fabric filters (FFs) represents the most mature and potentially most cost-effective control technology for power plants. However, all of the work prior to this program was conducted using bench-scale and pilot experiments. Although these reduced-scale programs provided valuable insight into many important issues, they cannot fully account for impacts of additional control technology on plant-wide equipment.

Therefore, it was necessary to scale up the technology and perform full-scale field tests to document actual performance levels and determine accurate cost information. Under a DOE/NETL cooperative agreement, ADA-ES, Inc., worked in partnership with PG&E National Energy Group (NEG), We Energies (a subsidiary of Wisconsin Energy Corp.), Alabama Power Company (a subsidiary of Southern Company), and EPRI on a field evaluation program of sorbent injection upstream of existing particulate control devices for mercury control[2–4]. Other organizations providing cost share to this program were Ontario Power Generation, FirstEnergy Corp., Hamon Research-Cottrell, Tennessee Valley Authority (TVA), Kennecott Energy Company, and Arch Coal, Inc. Team members include EPRI, Apogee Scientific, Inc., URS Corporation, Energy and Environmental Strategies, Quinapoxet Solutions, and Reaction Engineering International (REI).

This report is the Final Report presenting results from testing conducted at PG&E NEG Brayton Point Station in the summer of 2002.

DESCRIPTION OF OVERALL PROGRAM

The Department of Energy's National Energy Technology Laboratory (DOE/NETL) was the primary funding agency on an industry cost-shared test program to obtain the necessary information to assess the costs of controlling mercury from coal-fired utility plants that do not have scrubbers for SO_2 control. The method for mercury control evaluated in this program was the injection of dry sorbents, such as activated carbon, upstream of the existing particulate control device on a full-scale system. The four sites, shown in Table 1, fire a coal type and have particulate control equipment that are representative of 75% of the coal-fired generation in the United States.

Table 1. Test Site Description.

Test Site	Coal	Particulate Control
PG&E NEG, Salem Harbor	Low Subbituminous	Cold-Side ESP
PG&E NEG, Brayton Point	Low Subbituminous	Cold-Side ESP
We Energies, Pleasant Prairie	PRB (Subbituminous)	Cold-Side ESP
Alabama Power, Gaston	Low Subbituminous	Hot-Side ESP, COHPAC® FF

Brayton Point Unit 1 was of key interest for this evaluation because of its combination of firing low-sulfur bituminous coal with a cold-side ESP. This combination covers a wide range of coal-fired power plants operating in the eastern part of the U.S. Brayton Point had a unique configuration of two ESPs in series, which made an easier task of documenting the impacts of sorbent injection on ESP performance. Other attractive features for this test site included:

1. PG&E NEG was evaluating mercury control technologies to meet new state compliance regulations in 2007;
2. The second ESP in series could be treated in isolation;
3. Brayton Point Unit 1 utilizes an EPRICON SO_3 flue gas conditioning system, which allowed evaluation of the performance of sorbent injection with and without SO_3 flue gas conditioning; and
4. Long duct runs and test port configurations provided the ability to measure performance of sorbent injection across the second ESP and to measure in-flight mercury removal.

The overall program had 12 technical tasks. Tasks 2 through 9 were specific to each of the field evaluations and Tasks 1, 10, 11, and 12 were common tasks in support of all the test sites. The technical tasks are shown in Figure 1.

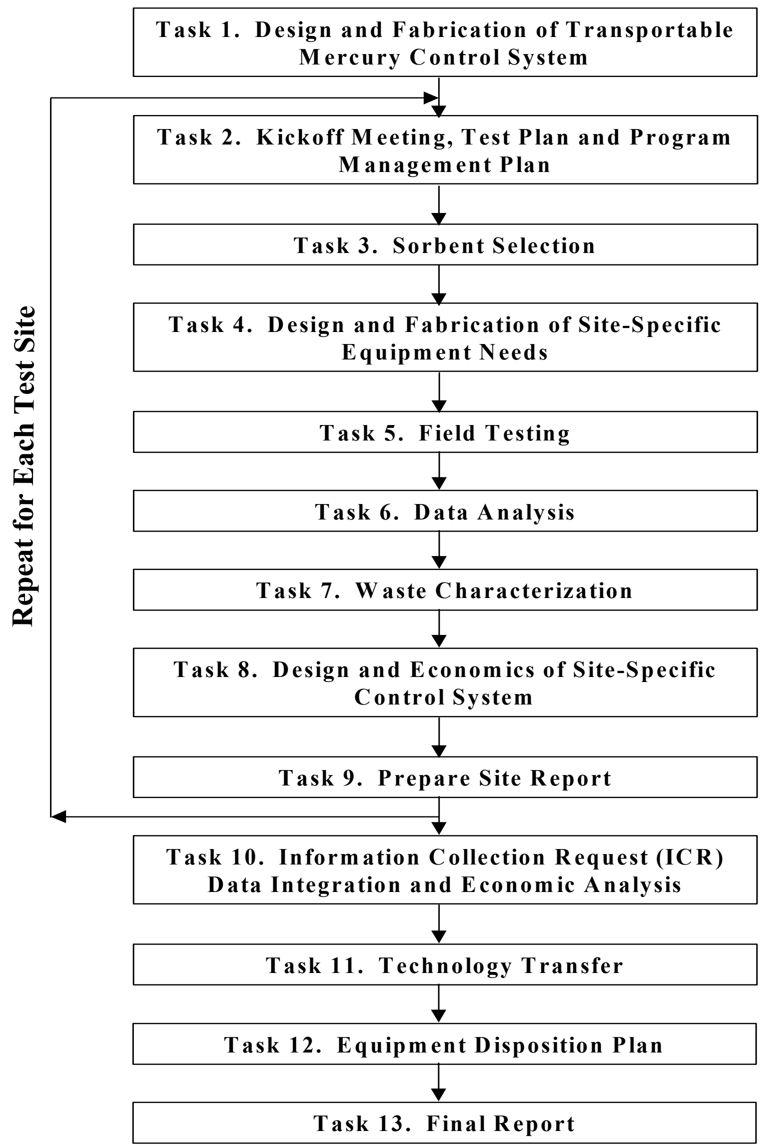

Figure 1. Outline of Overall Program Technical Tasks.

This program was funded through a cooperative agreement between the DOE/NETL and ADA-ES. The agreement included a requirement that industry cost-share the program at a minimum of 33%. Under the DOE/NETL cooperative agreement, ADA-ES worked in partnership with PG&E NEG, Wisconsin Electric Company (a subsidiary of Wisconsin Energy Corp.), Alabama Power Company (a subsidiary of Southern Company), and EPRI. Significant cost-share was provided by industry for the Brayton Point tests. Cost-share partners were:

- PG&E National Energy Group
- NORIT Americas, Inc.
- Ontario Power Generation
- Tennessee Valley Authority
- Southern Company
- Arch Coal, Inc/
- Wisconsin Electric Company
- ADA-ES, Inc.

BRAYTON POINT PROJECT OBJECTIVE AND TECHNICAL APPROACH

The overall objectives of testing at Brayton Point Unit 1 were to determine the cost and impacts of sorbent injection into the cold-side ESP for mercury control. ESP performance, auxiliary equipment operation, and waste disposal were some of the impacts evaluated. Testing was conducted on one-half of the gas stream, nominally 125 MW.

To achieve the overall objectives, the program was designed with an extensive field evaluation, laboratory testing, and analysis effort. This report presents the results of these efforts.

SITE DESCRIPTION

PG&E National Energy Group owns and operates Brayton Point Station located in Somerset, Massachusetts. There are four fossil-fuel-fired units at the facility designated as Units 1, 2, 3, and 4. In 1982, three of the four units, (Units 1, 2, and 3) were converted from oil to coal. These units fire low-sulfur, bituminous coals. Unit 1, which was the test unit, has a tangentially fired boiler rated at 245 net MW.

The primary particulate control equipment consists of two cold-side ESPs in series, with an EPRICON flue gas conditioning system that provides SO_3 for fly ash resistivity control. The EPRICON system is not used continuously, but on an as-needed basis. The first (old) ESP in this particular configuration was designed and manufactured by Koppers. The Koppers ESP has a weighted wire design and a specific collection area (SCA) of 156 ft^2/1,000 acfm. The second (new) ESP in the series configuration was designed and manufactured by Research-Cottrell. The second ESP has a rigid electrode design and an SCA of 403 ft^2/1,000 acfm. Total SCA for the unit is 559 ft^2/1,000 acfm. The precipitator inlet gas temperature is nominally 280ºF at full load.

The first precipitator consists of four parallel chambers, each with 28 gas passages 24' long at 10" centers. Each chamber is further divided into three collecting surface fields. The first ESP has a total of 12 transformer/rectifier (T/R) sets.

The second precipitator consists of two parallel chambers. Each chamber is subdivided into 38 gas passages 54' long at 12" centers. The chambers are then divided into six collecting surface fields. The second ESP contains a total of 24 T/R sets.

Hopper ash from both precipitators is combined in the dry ash-pull system. The ash is processed by an on-site carbon separation system to reduce the carbon content to approximately 2%. This processed ash is sold as base for concrete and is considered a valuable product for the Brayton Point Station. The remainder of the higher carbon ash is a disposable waste. One precipitator's ash can be isolated from the balance of the unit; however, this is a labor-intensive procedure.

A summary of important descriptive parameters for Brayton Point Unit 1 is presented in Table 2.

Table 2. Site Description Summary, Brayton Point Unit 1.

Parameter Identification	Description
Process	
Boiler Manufacturer	C-E Tangential, Twin Furnace
Burner Type	C-E LNCFS III (32 burners)
Low-NO_x Burners	Yes
Steam Coils	Yes
Over Fire Air	Yes
NO_x Control (Post Combustion)	None
Temperature (APH Outlet)	280ºF
Coal	
Type	Eastern Bituminous
Heating Value (Btu/lb)	12,319
Moisture (%)	6.6
Sulfur (%)	0.72
Ash (%)	11.32
Hg (µg/g)	0.05
Cl (%)	0.08
Type	Cold-Side ESPs in series
ESP #1 Manufacturer	Koppers
Design	Weighted Wire
Specific Collection Area (ft^2/1,000 afcm)	156
ESP #2 Manufacturer	Research-Cottrell
Design	Rigid Electrode
Specific Collection Area (ft^2/1,000 afcm)	403
Flue Gas Conditioning	SO_3 Injection, EPRICON

Sorbent for mercury control was injected into the ductwork in between the two electrostatic precipitators. Only one of the two inlet precipitator ducts was treated, nominally 125 MW. This met DOE's requirement to evaluate units up to 150 MW. This particular ESP configuration allowed for measurement of in-flight mercury removal efficiency between the two ESPs and mercury removal efficiency across each ESP.

Figure 2 presents a diagram of the particulate control equipment at Brayton Point. This figure shows the two ESPs in series.

Figure 3 is a plan view of the precipitators and depicts flue gas flow through the system. It also shows mercury measurement locations.

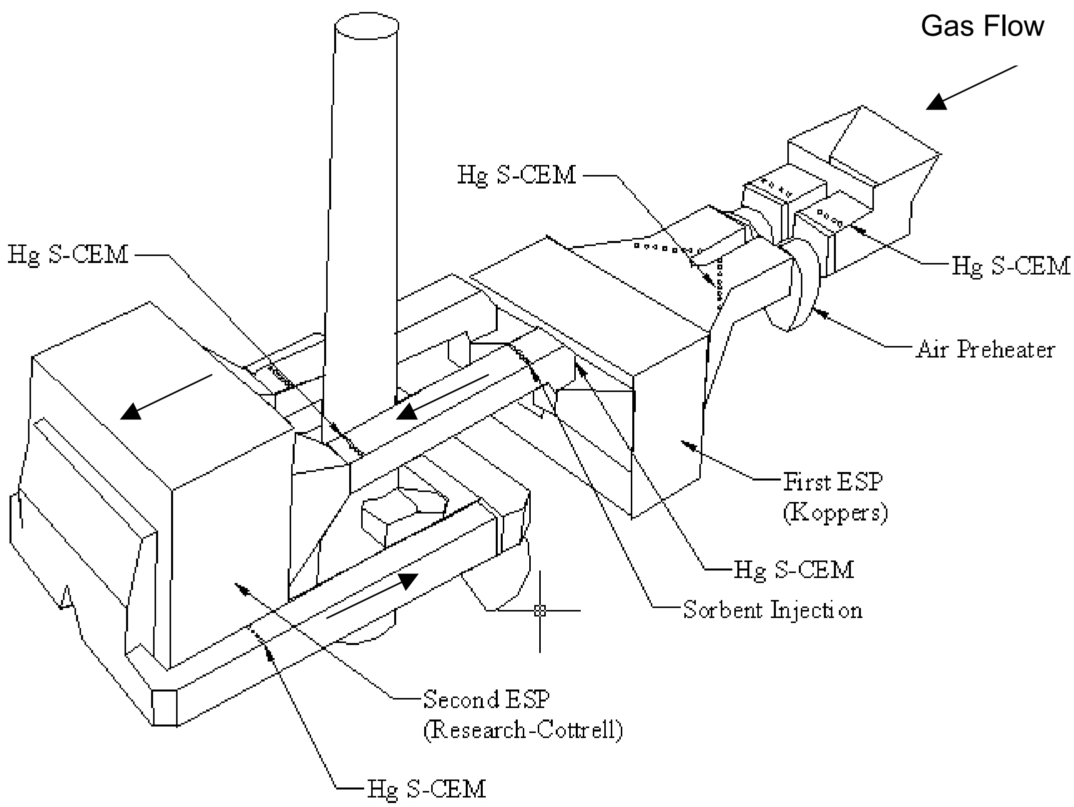

Figure 2. Isometric View of Precipitator Arrangement at Brayton Point Unit 1.

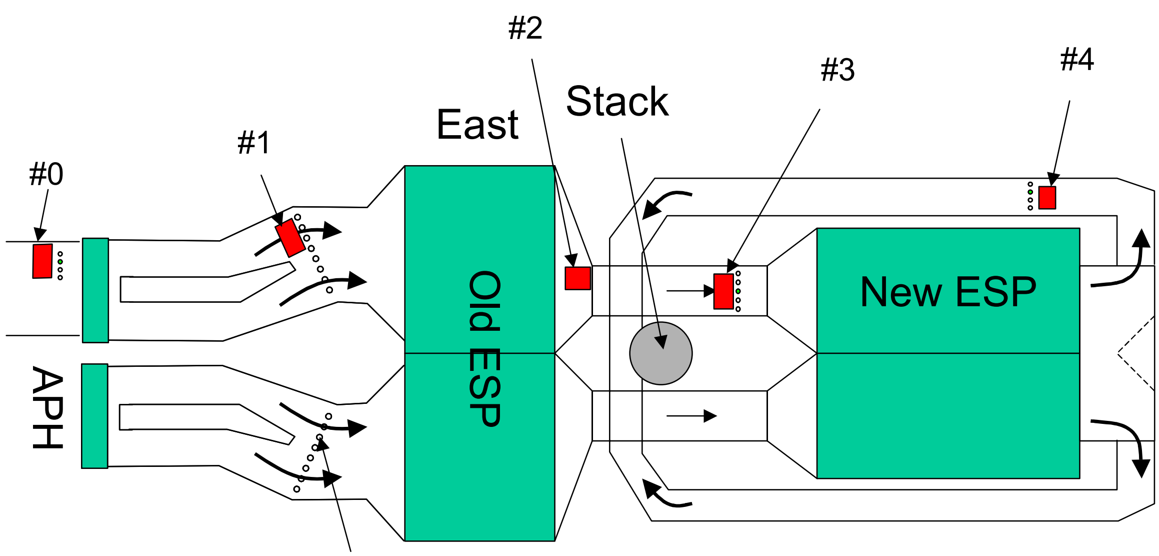

Figure 3. Plan View of Precipitator Arrangement and Hg S-CEM locations at Brayton Point.

FIELD EVALUATION

The critical elements of the site evaluation were the actual field tests and measurements that relied upon accurate, rapid measurements of mercury concentration, and an injection system that realistically represented commercially available technology.

Near real-time, vapor-phase mercury measurements were made using semi-continuous emissions monitors (S-CEM) designed and operated by Apogee Scientific, Inc. This instrument was developed with EPRI funding to facilitate EPRI research and development efforts[5]. Multiple S-CEMs were used throughout the system. The S-CEMs operated continuously for over six weeks, providing speciated, vapor-phase mercury concentrations at the inlet and outlet of COHPAC®.

NORIT Americas supplied a portable, dilute-phase pneumatic injection system that is typical of those used at Municipal Solid Waste (MSW) facilities for mercury control with activated carbon injection. ADA-ES designed the distribution and injection components of the system as well as remote control and load following capabilities.

A Test Plan for this program at Brayton Point was developed prior to commencing testing, and is included in Appendix A. Meetings were held with plant, project, and environmental personnel to finalize the scope and logistics of the test program. Testing that had been performed at Brayton Point in June 2001 provided the basis for development of this test plan.

The overall schedule for equipment installation and tests conducted for the Brayton Point Unit 1 field evaluation is shown in Table 3.

Table 3. Schedule of Brayton Point Unit 1 Mercury Control Evaluation.

Test Description	Dates (2002)
Sorbent Screening Tests (field)	February
Equipment Installation	April–May
Preliminary S-CEM measure	June 1–5
Baseline Tests	June 6–7
Check-Out and Initial Sorbent Injection	June 9
Parametric Test Week 1	June 17–22
Parametric Test Week 2	June 24–30
Parametric Test Week 3	July 1, 2, 11, 12
Long-Term Test (DARCO FGD)	July 15–24
Ash/Sample and Data Analyses	August–November

Site-Specific Equipment Description

Sorbent requirements for various levels of mercury control were predicted based on data collected during the Pleasant Prairie field evaluation. The original test plan called for sorbent injection concentrations of 1, 3, and 10 lbs/MMacf. Practical limits associated with bulk handling of sorbents, storage requirements, and increased loading to the ESP were also considered. Rates used to design equipment for the Brayton Point test are presented in Table 4.

Table 4. Predicted Injection Rates for FGD Carbon on One-Half Flue Gas Stream at Brayton Point.

Target Hg Removal Efficiency (%)	Predicted Injection Concentration (lbs/MMacf)	Predicted Injection Rate* (lbs/hr)
40	1	30
50	3	90
70	10	300

** Injection rate based on nominal flow at full load of 500,000 acfm.*

The transportable sorbent injection system was provided by NORIT Americas and consisted of a bulk-storage silo and twin blower/feeder trains each rated at 750 lbs/hr. Sorbents were delivered in bulk pneumatic trucks and loaded into the silo, which was equipped with a bin vent bag filter. From the two discharge legs of the silo, the sorbent was metered by variable speed screw feeders and was discharged into eductors that provided the motive force to carry the sorbent to the injection point. Regenerative blowers provided the conveying air. A programmable logic controller (PLC) system was used to control system operation, adjust injection rates, and receive boiler load signals from the plant.

Figure 4 is a photograph of the sorbent silo and feed train installed at Brayton Point. This figure also displays the Hg S-CEM locations. Flexible hoses carried the sorbent from the feeders to distribution manifolds located in between the two precipitators, feeding the injection probes. The injection location consisted of eight injection probes with each manifold supplying four injection probes.

In preparation for the field evaluation at Brayton Point, one set of test ports was added. This configuration of test ports, as seen in Figure 4, provided the ability to measure mercury removal efficiencies across both precipitators as well as in-flight mercury capture.

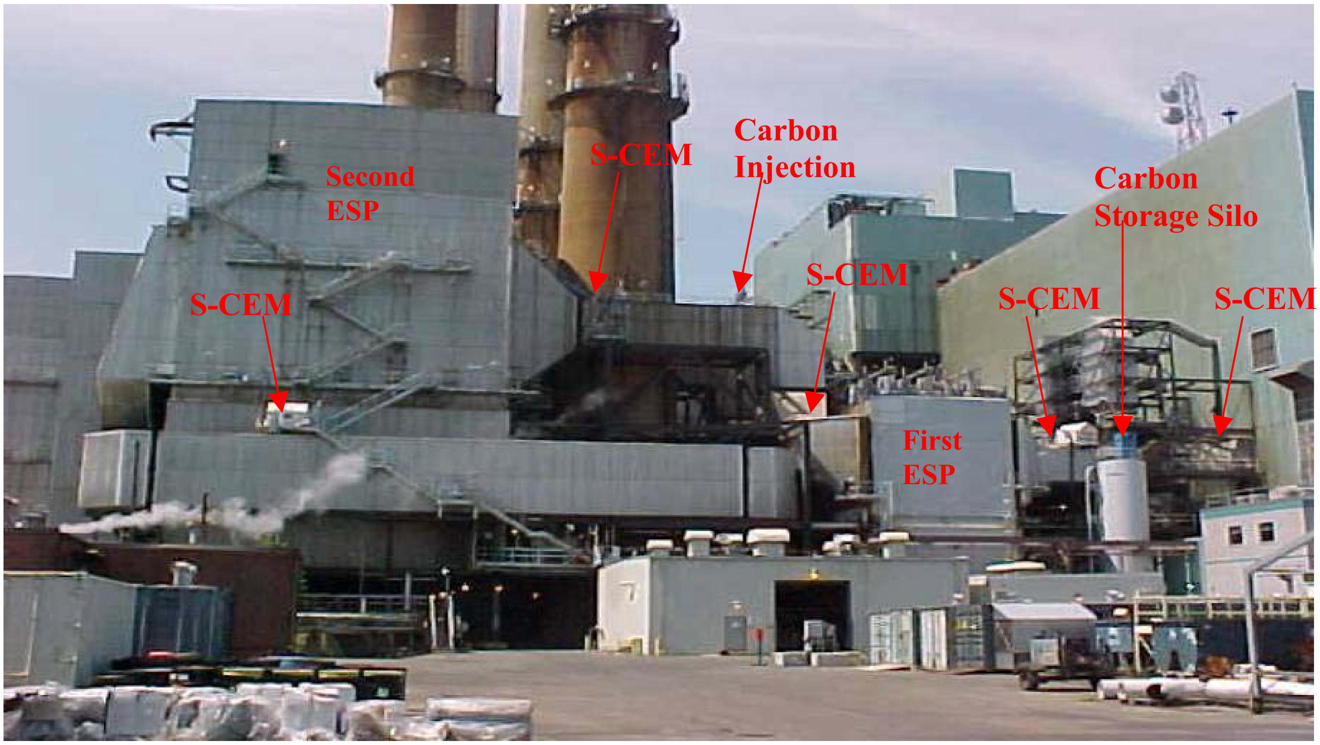

Figure 4. Carbon Injection Storage Silo and Sampling Locations at Brayton Point Unit 1.

Description of Field Tests

The field tests were separated into four different test phases:

- Sorbent Screening
- Baseline
- Parametric Tests
- Long-Term Tests

Test methods are described first, and then each of these phases of testing is described in the subsections below. Results from the laboratory and field tests are presented in the separate "Brayton Point Test Results" section that follows.

1. Test Methods Used in Field Testing at Brayton Point

For testing at Brayton Point Unit 1, the team generated a comprehensive Test Plan (Appendix A), which includes test methodology and quality control procedures. The test company, TRC Environmental Corporation (TRC), prior to testing provided detailed descriptions of the Ontario Hydro method field sampling and laboratory analyses. Appendix C of the Test Plan provides a detailed description of the S-CEM used for continuous mercury monitoring. These were the two primary methods used to measure mercury during the field tests.

TRC also conducted EPA Method 29 measurements during the long-term tests to quantify multi-metal emissions at the outlet of the second (new) ESP.

Sample locations placed strategically throughout the system allowed for mercury removal efficiency measurements across each particulate collection device. A list of measured parameters and their sample locations is given in Appendix D.

2. Sorbent Selection and Screening

Because of the economic impact of sorbent cost on the overall cost of mercury control, it is desirable to find less expensive sorbents. Many groups, including team members EPRI, URS, and Apogee, have conducted extensive studies on this issue and have developed methods to quickly and economically screen potential sorbents.

The test plan included time to evaluate several sorbents. Alternative sorbents were chosen from several different potential sorbent types and suppliers. Brayton Point utilizes an on-site carbon separation technology supplied to them by Separation Technologies, Inc. (STI). Because Brayton Point ash LOI is typically between 6 and 10%, it was of interest to evaluate whether, by using this equipment, ash could be collected from the precipitators and processed so that the final product contained 80% carbon by weight, thus providing a possible mercury sorbent.

The procedure for sorbent screening was first to assess whether a sorbent met the economic and availability criteria described below, then to include the sorbent in laboratory screening and/or slipstream screening tests to determine its capacity. If initial screening showed good results and the sorbent was available, more extensive field testing, including duct injection, was considered.

Sorbent Selection Criteria

The future market for mercury sorbents is potentially very large and this program provided the first opportunity for suppliers to have sorbents evaluated at full scale. To follow the intent of NETL in choosing sorbents (to test commercially or near commercially-available products), a sorbent selection criterion was developed so that sorbent vendors/developers could clearly understand the needs and requirements of this program. A draft of the sorbent selection criteria is included in Appendix B of the Test Plan. In summary, an alternative sorbent supplier had to show that the sorbent would:

1. Be less expensive than FGD carbon;
2. Be available in quantities of at least 15,000 lb and 250,000 lb for site tests;
3. Be available in sufficient quantities to supply at least 100 tons per year by 2007; and
4. Have a capacity of at least 100 μg/g as measured in the laboratory by URS.

URS conducted both the laboratory and slipstream measurements of sorbent adsorption capacity and provided technical expertise in interpretation of results. URS has determined the equilibrium adsorption capacity for a variety of sorbents as a function of mercury concentration, mercury type, flue gas temperature, and flue gas composition. Results from these tests and a description of the test device and procedures have been published previously[6–8].

3. Baseline Testing

After equipment installation and checkout, a set of baseline tests was conducted June 6–7, 2002. During this test, boiler load was held steady at "full-load" during testing hours, nominally 8:00 a.m. to 6:00 p.m. Both the S-CEMs and the Ontario Hydro method were used to measure mercury. The Ontario Hydro tests were conducted at the inlet to the first ESP and the outlet of the second ESP. Prior tests conducted at Brayton Point's Unit 1 have shown a wide range of mercury removal efficiencies ranging from 29–75%.

In addition to monitoring mercury removal, it was also important to document the performance of the ESP with and without sorbent injection. This is critical to the success of sorbent injection for mercury control at Brayton Point. All tests, including baseline, parametric, and long-term, included monitoring of ESP performance. The primary performance indicator for an ESP is power level. The higher the power level, the better the performance. Power is measured in kW and was monitored throughout all testing. Changes in particulate matter characteristics such as resistivity can affect ESP performance. Throughout the field evaluation, sorbent injection into the ESP did not have any detrimental impacts on ESP performance. Trending graphs representing power levels in the ESP during the full-scale evaluation are presented later in the Test Results section.

During the baseline tests, daily samples of coal and ESP ash were collected from each of the five hoppers on the testing side of the two precipitators. A layout of the precipitator hoppers and fields can be seen in Figure 5.

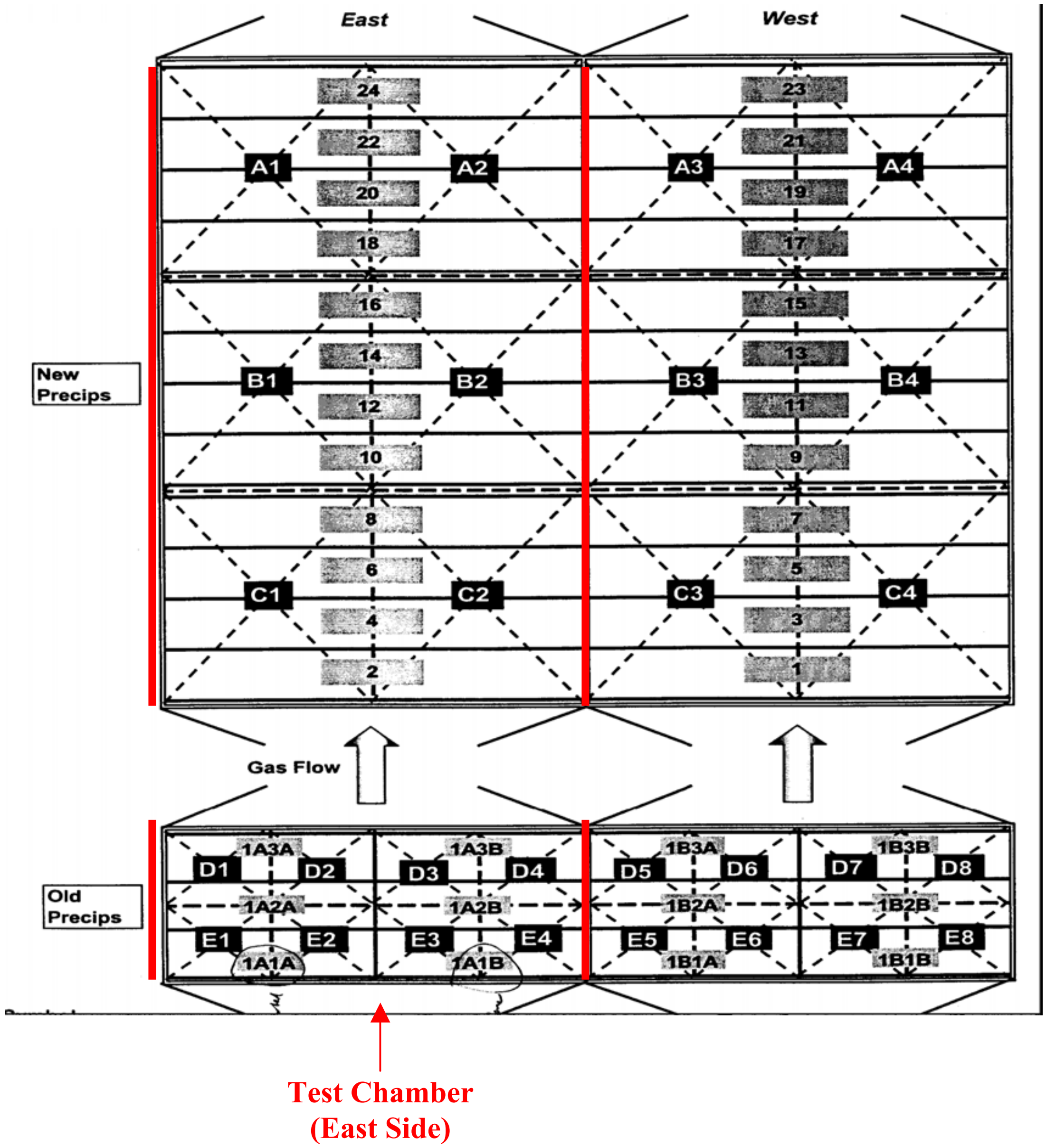

Figure 5. Unit 1 Precipitator Fields and Ash Hopper Arrangement.

4. Parametric Testing

A series of parametric tests was conducted to determine the optimum operating conditions for several levels of mercury control. Primary variables were:

- Injection concentration
- Carbon type (five types were tested)
- SO_3 flue gas conditioning on/off
- Injection lance design

In all, 20 different parametric conditions were tested. A summary of the parametric tests is presented in Table 5 and a more detailed description of the sorbents can be found in the Test Results section, later in this report. “Standard” conditions for these tests were with the boiler at full load operation and SO_3 conditioning on. Exceptions to the standard conditions are noted in the table. Each condition was run for a minimum of six hours.

During the parametric tests, the S-CEMs were used to quantify mercury control effectiveness of each tested condition. In addition, the impact of sorbent injection on the performance of the ESP was monitored.

Table 5. Summary of Parametric Test Conditions.

Test Series	Carbon Name	Target Injection Concentration (lbs/MMacf)	Testing Conditions
1–4	FGD	1, 3, 10, 20	Standard
5–6	SAI-B	3, 10	Standard
7–8	SAI-B	10, 20	Multiple Nozzle Lance
9–11	CC	3, 10, 20	Standard
12–14	HOK300	3, 10, 20	Standard
15–16	FGD	10, 20	EPRICON Off
17–18	FGD	7, 15	Standard
19–20	LAC	3, 10	EPRICON Off

5. Long-Term Performance Tests

Long-term testing under optimum conditions, as determined from the parametric tests, was performed to gather data on:

- Mercury removal efficiency over time.
- The effects of sorbent injection on ESP performance, ash quality, and balance-of-plant equipment.
- Operation of the injection equipment to determine the viability and economics of the process.

The original test plan called for injecting sorbents at one condition, 24 hours/day, for up to two weeks to obtain the highest mercury removal rates possible within equipment limitations. However, results from the parametric tests showed significant mercury removal at the target injection concentrations of 10 and 20 lbs/MMacf. This raised interest in the long-term performance under these conditions. The long-term test was divided into two injection periods, each lasting approximately four to five days, to determine:

5. The ability to capture mercury at the injection concentration of 10 lbs/MMacf (during the parametric testing series, this particular injection concentration showed mercury removal efficiencies in the range of 60–73%).

6. Mercury removal and impact on ESP performance at a high sorbent injection concentration (an injection concentration of 20 lbs/MMacf was chosen because, during the parametric testing series, this injection concentration resulted in a mercury capture of >90%).

NORIT's DARCO FGD activated carbon was chosen as the sorbent for these tests. Similar to the baseline test series, mercury was measured by both the S-CEMs and Ontario Hydro. The Ontario Hydro measurements were performed at both injection concentrations. ESP performance, coal and fly ash samples, plant CEM, and plant operational data were collected during the long-term testing period. Full-load boiler conditions were held between the hours of 7:00 a.m. to 8:00 p.m., with load under dispatch control at other times, except for the testing period when the Ontario Hydro tests were conducted and full load was maintained 24 hours/day. Table 6 presents the schedule for the long-term tests and the goals associated with each condition.

Table 6. Long-Term Test Conditions and Goals.

Dates	Target Injection Concentration	Test Goals
7/15/02–7/20/02	10 lbs/MMacf	1. Measure mercury removal at medium injection rate
7/20/02–7/24/02	20 lbs/MMacf	1. Measure mercury removal at a high injection rate 2. Evaluate ESP performance with increased loading 3. Evaluate the balance-of-plant equipment and performance of ACI system

BRAYTON POINT UNIT 1 TEST RESULTS

Field-testing on Brayton Point Unit 1 was conducted between February and July 24, 2002. A summary of the test series and dates of testing were presented earlier in Table 2.

Results are presented separately for each of the series of tests in the subsections below. Results from coal and ash analyses for all test series are presented and discussed together under "Coal and Ash Characterization." Cost data is provided in the final subsection "Economic Analysis." Conclusions are summarized in the final section.

SORBENT SCREENING TEST RESULTS

At Brayton Point, mercury adsorption tests were carried out on a slipstream of flue gas upstream of the first precipitator. Testing was conducted, when possible, with and without SO_3 injection. Eight coal-derived sorbents, two fly ash-based sorbents, one tire-derived sorbent, and one zeolite-based sorbent were each tested at a temperature of 275ºF. The results of all field sorbent screening tests are shown in Table 7.

Table 7. Results of Fixed-Bed Screening Tests at Brayton Point.

Sorbent/Supplier	Base	Adsorption Capacity SO_3 Off (µg Hg/g)[1]	Adsorption Capacity SO_3 On (µg Hg/g)[1]
FGD/NORIT Americas	Lignite	4,314	1,380
FGL/NORIT Americas	Lignite	4,281	694
GAL/Donau Carbon	Lignite		1,745
HOK300/Donau Carbon	Lignite	4,786	
AFR-2/Advance Fuel Research	Tire Derived		538
CC/CARBOCHEM	Bituminous	1,948	
SAI-B/Superior Adsorbents	Bituminous		1,799
SorbTech-I/Sorbent Technologies		62	
SorbTech-L/Sorbent Technologies		2,091	
STI020115-2/ Separation Technologies, Inc.	BP Ash 80% Carbon	>109	
STI020121-3/ Separation Technologies, Inc.	SH Ash 80% Carbon	245	
AANP Zeolite/URS		7	

1. Normalized to 50 µg/Nm³

The major conclusions from the fixed-bed tests were:

- Activated carbons are capable of achieving high (>4,000 μg mercury/g) mercury adsorption capacities in Brayton Point Unit 1 flue gas without SO_3.
- SO_3 appears to inhibit carbon adsorption and, with certain sorbents, decreased the adsorption capacity to zero. With the activated carbon products, the presence of SO_3 in the flue gas decreased the adsorption capacity in some cases by a factor of six; however, the measured adsorption capacity was still above the threshold capacity (nominally 150 μg/g for an ESP). Therefore, performance of these sorbents should not be impacted[9].
- Only one of the fly ash-based sorbents tested showed an adsorption capacity greater than 150 μg/g.
- The zeolite-based sorbent showed a low adsorption capacity in the Brayton Point flue gas, thus, this particular sorbent was not chosen for full-scale testing.

BASELINE TEST RESULTS

During baseline tests, June 6–7, 2002, mercury in the flue gas was measured with the S-CEMs and by the Ontario Hydro test method. In addition, coal and ash samples were collected.

Preliminary results from baseline tests were summarized in a memo dated June 10, 2002. This memo is included for reference in Appendix B. Baseline test conditions were normal, full-load operation.

Ontario Hydro results are shown in Table 8. The measurements indicate an average native mercury removal efficiency of 90.8% from inlet to the first ESP (Loc 1) to outlet of the second ESP (Loc 4). No elemental mercury was detected in any sample. A large portion (~95%) of the total mercury was in the particulate form at the inlet test location, indicating the mercury was either adsorbed onto the ash in the flue gas or in the sample train. This is shown in Table 7 as particulate mercury. This removal efficiency seemed extraordinarily high, as previous measurements had shown removal efficiencies between 35 and 75% (TRC and EPA's ICR data).

Table 9 shows the approximate vapor-phase mercury levels present in the flue gas, as measured by the S-CEMs, during the Ontario Hydro tests. The inlet concentration was unexpectedly low at <0.5 μg/dncm, but helps to explain the high baseline removal efficiency. Coal samples collected during baseline tests and analyzed for mercury showed an average concentration of 0.045 μg/g. At Brayton Point, a coal mercury level of 0.045 μg/g is equivalent to a total mercury concentration of about 4–5 μg/dncm @ 3% O_2 in the flue gas. These coal data verify the Ontario Hydro test inlet concentration of nominally 5 μg/dncm. The Ontario Hydro data also indicated that nearly 95% of the mercury was in the particulate form. The coal and S-CEM data support a conclusion that the majority of the mercury was in the particulate phase in the flue gas, rather than the particulate mercury being an artifact of the test procedure. During these baseline tests, the combination of coal and operating conditions appear to have resulted in a high percentage of particulate-phase mercury. With the very large, high-efficiency ESP at Brayton Point, it is reasonable to conclude the >90% of the particulate-phase mercury could be collected in the ESP, resulting in a 90% removal of total mercury.

Table 8. Speciated Mercury Measured by Ontario Hydro Method, Baseline Conditions (Without Sorbent Injection). Average of Three Runs, Brayton Point Unit 1, June 2002.

	Particulate (μg/dncm)	Elemental (μg/dncm)	Oxidized (μg/dncm)	Total (μg/dncm)
ESP Inlet	4.6	ND <0.21	0.26	5.1
ESP Outlet	<0.007	ND <0.29	0.18	0.48
Removal Efficiency (%)	99.8	N/A	30.8	**90.6%**

Note: all mercury numbers are μg/dscm at 32ºF, 3% O_2.

Table 9. Vapor-Phase Mercury Measured S CEMs, Baseline Conditions (Without Sorbent Injection). June 6–7, 2002.

Inlet to Old ESP Total Vapor-Phase Hg Concentration μg/Nm^3	Outlet to New ESP Total Vapor-Phase Hg Concentration μg/Nm^3
~0.4–0.5	~0.1–0.2

PARAMETRIC TEST RESULTS

Based on several factors ranging from availability to cost, six different sorbents from the screening tests were selected for use in the full-scale test. However, due to certain circumstances, two of the six participants declined to participate in the evaluation. The Hg project team decided to add another carbon-based sorbent supplied by EPRI. Table 10 provides a description of the five sorbents that were evaluated in the parametric tests at Brayton Point:

Table 10. Description of Carbons Evaluated in the Parametric Tests.

Name	Supplier	Description	Surface Area (m^2/g)	Particle Size
DARCO FGD	NORIT Americas	Lignite–AC	600	15–20 μm MMD
CC	CARBOCHEM	Bituminous–AC	NA	<325 Mesh
SAI-B	Superior Adsorbents	Bituminous–AC	1,000	<325 Mesh
HOK300	Donau Carbon	Lignite–AC	300	18 μm MMD
LAC	EPRI	Lignite–AC	310	19.2 μm MMD

The DARCO FGD activated carbon product supplied by NORIT Americas has been the benchmark sorbent used in research and testing specific to mercury control up to this date. Tests showed very high adsorption capacity with and without SO_3 conditioning. This particular sorbent was tested at our previous two field test sites: We Energies Pleasant Prairie Power Plant and Alabama Power Plant Gaston.

CARBOCHEM is a privately held corporation that provides industrial chemicals around the world with an emphasis on activated carbon products. Their CC product is manufactured from a bituminous coal and showed an adsorption capacity >1,900 µg/g without SO_3 conditioning.

The SAI-B supplied by Superior Adsorbents, Inc., had an excellent adsorption capacity with the presence of SO_3 in the flue gas. It also had competitive pricing and was able to meet the selection criterion.

Donau Carbon supplied the HOK300 sorbent, which is manufactured in Germany. This particular sorbent is primarily used in municipal solid waste incinerators in Europe to collect different pollutants, including mercury. This sorbent also showed high adsorption capacity without SO_3 conditioning.

The final product that was chosen for full-scale evaluation was a developmental activated carbon product, LAC, supplied by EPRI. It is a mildly activated carbon made from lignite. This particular sorbent was not tested in the fixed-bed apparatus used for sorbent screening in February 2002. Because a couple of the sorbent manufacturers declined to participate, the Hg project team decided to add the LAC sorbent to the test program.

Parametric testing evaluated mercury removal as a function of injection concentration, sorbent type, SO_3 conditioning and injection lance design. The impact of sorbent injection on ESP performance was closely monitored. The Hg S-CEM test locations allowed for measurements of mercury capture across the first precipitator, in-flight mercury capture by the sorbent, mercury capture across the second precipitator, and overall vapor-phase mercury capture across the system.

Results from parametric test series were summarized in memos dated June 20, June 27, and July 10, 2002. These memos are provided in Appendix C. Major results and observations are presented here.

FGD DARCO Parametric Tests – Week 1

In the first week of parametric tests, DARCO FGD was tested at four different injection concentrations: 1, 3, 10, and 20 lbs/MMacf.

A summary of the removal efficiencies as measured by S-CEMs during the first week of parametric testing is presented in Table 11. These same data are presented graphically in Figure 6. Mercury removal was measured across the second ESP and therefore only measures the incremental removal achieved by injecting the mercury adsorbing sorbents. Minimal incremental removal across the second ESP was seen at an injection concentration of 1 lb/MMacf. Removal increased with injection concentration, with 90% incremental control at an injection concentration of 20 lbs/MMacf.

When injection started, the impact on outlet mercury concentration was immediate. Recovery back to the inlet concentration after stopping sorbent injection was only partial, with full recovery taking several hours.

Table 11. S-CEM Data Collected during Week 1 Parametric Tests.

Date	Sorbent	Injection Concentration (lbs/MMacf)	Incremental Removal Across Second ESP (%)
6/17/2002	FGD	3	35
6/18/2002	FGD	10	73
6/19/2002	FGD	1	13
6/19/2002	FGD	20	90
6/20/2002	FGD	10	70

Throughout the first week of parametric testing, the EPRICON SO_3 flue gas conditioning system was in service. Unit 1 was held steady at full-load operating conditions (nominally ~250 MWe) during the testing period. Inlet flue gas temperatures were nominally 250ºF.

During Week 1 of parametric testing, gaseous mercury concentrations ranged from 2.9–4.8 µg/dncm (2.1–3.5 lbs/TBtu) upstream of the first ESP. At the inlet to the second ESP, gaseous mercury concentrations ranged from 2.4–3.4 µg/dncm (1.7–2.5 lbs/TBtu). The average mercury capture across the first ESP was 28% during the first week of parametric testing, which was very different than the baseline testing conditions when over 80% mercury removal was measured across the first ESP.

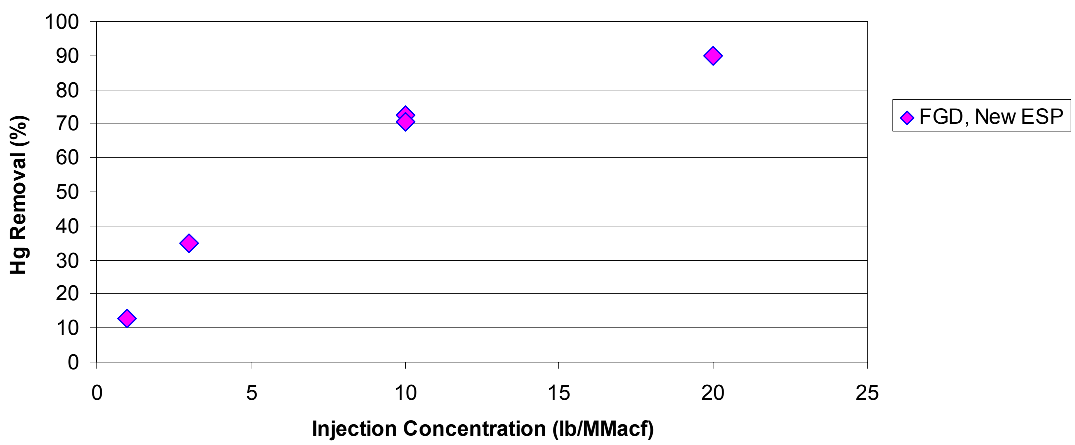

Figure 6. Week 1 Parametric Results – FGD Sorbent.

Alternate Sorbents – Week 2

In addition to the NORIT DARCO FGD product, sorbents from other suppliers were tested. Four additional sorbents were tested and each was tested at injection concentrations of 3, 10, and 20 lbs/MMacf.

Figure 7 is a summary of the test results of the alternate sorbents. As seen on Figure 7, the relatively linear trend between injection concentration and Hg removal is similar to the trend seen with the FGD sorbent. At the high injection concentration, the alternate sorbents showed a Hg removal capture of 75–86%, compared to the FGD that showed a 90% Hg capture. The alternate sorbents had a moderate range of removal efficiencies at the lower injection concentration of 3 lbs/MMacf, ranging from 2–18%.

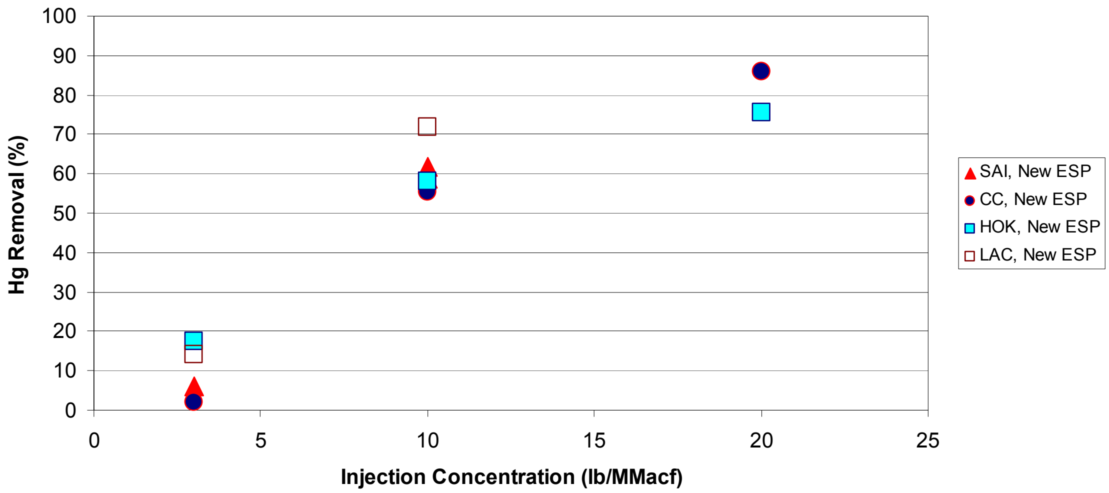

Figure 7. Alternate Sorbent Results – Week 2 Parametric Tests.

Additional Parametric Testing

Sorbent screening tests using URS' packed-bed test fixture showed that SO_3 conditioning significantly decreased the adsorption capacity of the carbon sorbents. This result created interest in evaluating whether a similar decrease in performance would be seen at full-scale. For this next set of tests, the EPRICON SO_3 flue gas conditioning system was turned off and FGD sorbent was injected at 10 and 20 lbs/MMacf. The Hg removal efficiencies across the second ESP at 10 and 20 lbs/MMacf were 71% and 93% respectively. Table 12 compares removal efficiencies with and without SO_3 conditioning.

Table 12. Results of SO_3 Conditioning – Week 3 Parametric Tests.

Sorbent	Injection Concentration	EPRICON SO_3 System (On/Off)	% Hg Removal Across Second ESP
FGD	10	On	70–73
FGD	10	Off	71
FGD	20	On	90
FGD	20	Off	93

Although there is limited full-scale test data with the EPRICON SO_3 system, there appears to be no detrimental impact from the flue gas conditioning system on the sorbent's ability to capture the gaseous mercury, even though the fixed-bed tests showed a decrease in adsorption capacity from >4,000 µg/g to 1,380 µg/g for FGD carbon.

Parametric Test Summary

The sorbent injection system supplied by NORIT Americas operated reliably during the parametric testing series. With each sorbent having different physical characteristics, both feed trains on the injection system were calibrated to ensure proper feed rates during testing. In addition to the calibration procedure, a 5-gallon sample of sorbent was collected during each delivery and logged into the sample database.

A summary of results from all the parametric tests is presented on Figure 8. This figure plots mercury removal efficiency as a function of sorbent injection concentration. The mercury removal data show incremental mercury removal across the second (new) ESP. The different symbols represent different test conditions including carbon type and when SO_3 conditioning was turned off. Hg removal efficiencies ranged from 2–35% at the lower sorbent injection concentration of 3 lbs/MMacf to 75–93% at the highest sorbent injection concentration of 20 lbs/MMacf.

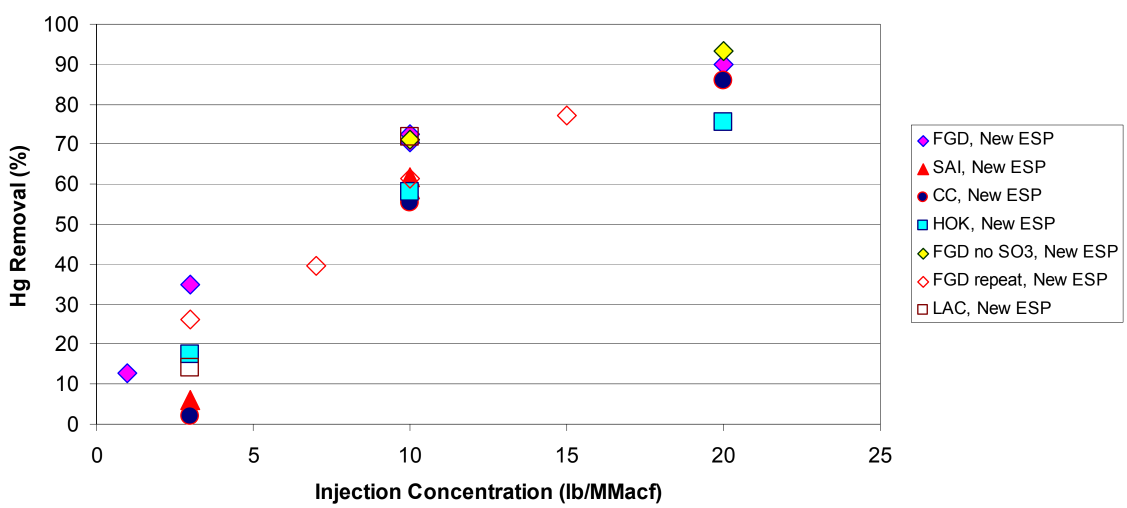

Figure 8. Mercury Removal Trends across Second ESP – Parametric Testing Summary.

Figure 9 presents a comparison of data collected during the parametric tests at Brayton Point, which fires a bituminous coal, and Pleasant Prairie, which fires a PRB coal. At Pleasant Prairie, mercury removal was limited to nominally 70% even when injection concentration was increased significantly. At Brayton Point, removal efficiency increased with injection concentration, which is what theory would predict. A halogen-deficient flue gas environment was found to limit the effectiveness of the activated carbon at Pleasant Prairie. At Brayton Point, there were sufficient halogens in the flue gas at all test conditions. For comparison purposes, the chlorine content of the Brayton Point coal was 1,300 to 1,600 ug/g (dry basis), while the chlorine content of the Pleasant Prairie coal was on the order of 10 ug/g (dry basis).

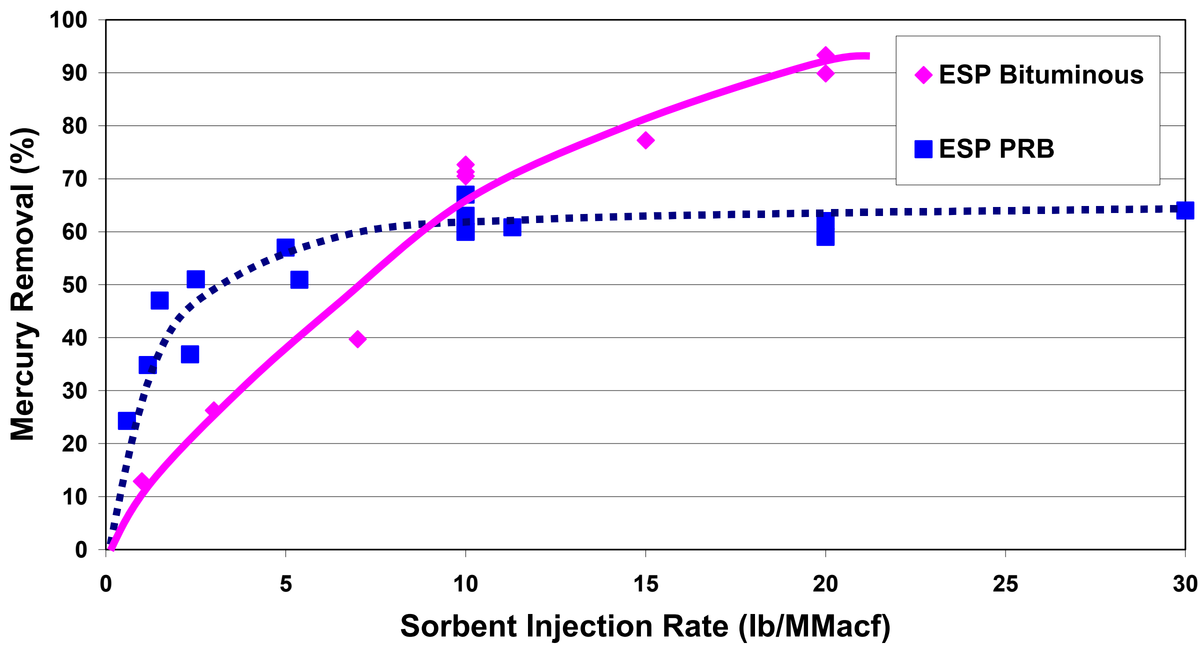

Figure 9. Comparison of Parametric Test Results at Pleasant Prairie (PRB Coal) and Brayton Point (Bituminous Coal).

One of the test objectives was to determine the impacts of sorbent injection into the ESP. During parametric testing, plant data were collected to monitor ESP performance and particulate emissions. The primary parameters were ESP electrical data (total power and secondary current and voltage) and stack opacity. Figure 10 presents total power on the control and test side of the ESP. At no time was there a period where total power degraded because of carbon injection. During the same period, stack opacity remained well below regulatory limits, even during periods of ACI up to 20 lbs/MMacf.

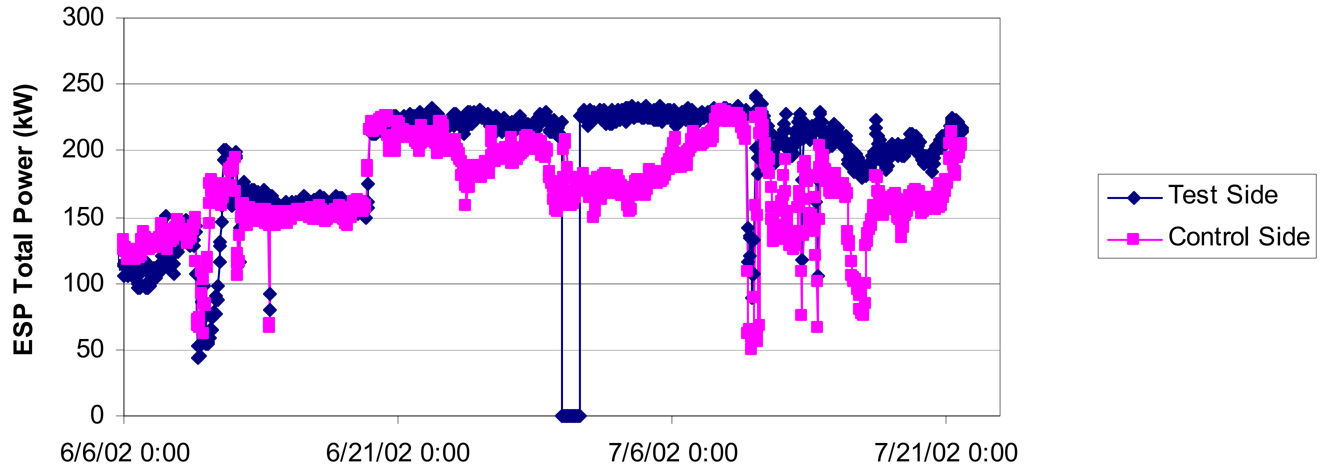

Figure 10. ESP Power Levels in the Second ESP.

LONG-TERM TEST RESULTS

The long-term tests were conducted over a 10-day period at two different sorbent injection concentrations. During the first five days of testing, DARCO FGD was injected continuously at a concentration of 10 lbs/MMacf. Upon completion of this test, the injection concentration was immediately increased to 20 lbs/MMacf and maintained at this rate for the rest of the long-term test.

During both periods of testing, vapor-phase mercury was measured with the Hg S-CEMs at the inlet and outlet of the second (new) ESP. Daily inlet and outlet mercury concentrations and calculated removal efficiencies across the second ESP can be seen in Table 13. Using these data, the average mercury removal was 91% during the 10 lbs/MMacf test and 98% during the 20 lbs/MMacf test.

Table 13. Daily Average Mercury Removal Measured by S-CEM during Long-Term Test.

Date	Injection Concentration (lbs/MMacf)	Inlet (Loc 2) µg/dscm	Outlet (Loc 4) µg/dscm	Outlet (Loc 4) lbs/TBtu	Removal Efficiency (%)
7/15/2002	10	2.2	0.47	0.34	79
7/16/2002	10	3.0	0.20	0.15	93
7/17/2002	10	3.2	0.21	0.15	93
7/18/2002	10	2.5	0.14	0.10	94
7/19/2002	10	3.1	0.15	0.11	95
7/20/2002	20	2.9	0.06	0.04	97
7/21/2002	20	4.0	0.05	0.04	98
7/22/2002	20	3.9	0.07	0.05	98
7/23/2002	20	2.6	0.05	0.04	98

To verify outlet S-CEM results, mercury was also measured by the Ontario Hydro method. Because of the unique configuration of the ESPs at Brayton Point, it was necessary to conduct the Ontario Hydro measurements at the inlet of the first (old) ESP and the outlet of the second (new) ESP.

Triplicate Ontario Hydro measurements were made at both injection concentrations. Results from these Ontario Hydro measurements are presented in Tables 14 and 15. The average inlet mercury concentrations were 9.1 and 7.6 μg/dncm for the 10 and 20 lbs/MMacf test series, respectively.

A significant fraction of the mercury species was measured to be in the particulate form. The particulate-phase mercury during these tests was most likely as mix of actual particulate-phase mercury in the flue gas and mercury that reacted with the particulate filter during sampling. During the long-term test, there was nominally 40–50% removal across the first ESP. Coal samples taken during this period had an average mercury level of 0.07 μg/g, or an equivalent total flue gas concentration of 6-8 μg/dncm, which correlates well with the inlet measurements.

Elemental mercury in every case (inlet and outlet) was below the method detection limit. Oxidized mercury was a small fraction of the total at the inlet, from 4 to 12%. The only detectable mercury at the outlet to the second ESP was oxidized mercury. The levels detected are very low and close to the detection limit of the method.

Table 14. Ontario Hydro Results from Long-Term Test on July 18–19, 2002, at Brayton Point; 10 lbs/MMacf ACI.

Inlet	**Particulate (μg/dncm)[1]**	**Elemental (μg/dncm)[1]**	**Oxidized (μg/dncm)[1]**	**Total (μg/dncm)[1]**	**Total (lbs/TBtu)**
Run 1	8.1	ND[2] <0.39	0.39	<8.9	<6.5
Run 2	8.6	ND[2] <0.27	1.25	<10.1	<7.4
Run 3	7.0	ND[2] <0.49	0.85	<8.3	<6.1
Average	**7.9**	**ND[2] <0.38**	**0.83**	**<9.1**	**<6.6**
Outlet					
Run 1	ND[2] <0.04	ND[2] <0.48	0.48	<1.0	<0.73
Run 2	ND[2] <0.03	ND[2] <0.30	0.17	<0.50	<0.37
Run 3	ND[2] <0.03	ND[2] <0.34	0.15	<0.52	<0.38
Average	**ND[2] <0.03**	**ND[2] <0.37**	**0.27**	**<0.67**	**<0.49**
Average RE %	**>99.6%**	**N/A**	**67.5%**	**~92.6%**	

Note 1: Normal: T = 32°F, Values corrected to 3% O_2.
Note 2: < values indicate measured value is below method detection limit.

Table 15. Ontario Hydro Results from Long-Term Test on July 22–23, 2002, at Brayton Point; 20 lbs/MMacf ACI.

Inlet	Particulate (µg/dncm)[1]	Elemental (µg/dncm)[1]	Oxidized (µg/dncm)[1]	Total (µg/dncm)[1]	Total (lbs/TBtu)
Run 1	5.1	ND[2] <0.33	1.53	<7.0	<5.1
Run 2	5.6	ND[2] <0.34	1.53	<7.5	<5.5
Run 3	7.8	ND[2] <0.31	0.26	<8.3	<6.1
Average	**6.15**	**ND[2] <0.33**	**1.11**	**<7.6**	**<5.6**
Outlet					
Run 1	ND[2] <0.04	ND[2] <0.24	0.09	<0.37	<0.27
Run 2	ND[2] <0.07	ND[2] <0.26	0.11	<0.44	<0.32
Run 3[3]	2.31	ND[2] <0.19	0.05	<2.55	<1.86
Average	**ND[2] <0.05**	**ND[2] <0.25**	**0.10**	**<0.40**	**<0.29**
Average RE %	**>99%**	**N/A**	**91%**	**~94.7%**	

Note 1: Normal: T = 32 °F, Values corrected to 3% O_2.
Note 2: < values indicate measured value is below method detection limit.
Note 3: The Run 3 Outlet particulate mercury measurement is an outlier when compared with the other five outlet measurements (Tables 14 and 15). This run is not included in the averages shown in this table.

As can be seen in Tables 14 and 15, the total mercury at the outlet for the third run in the 20 lbs/MMacf test is much higher than any of the other five outlet measurements. This is solely attributable to one of the triplicate tests, which detected 2.31 µg/dncm of particulate phase mercury at the outlet. This high value, among five other outlet runs that were all "not detect" on particulate-bound mercury, would have to be confirmed through further testing before any conclusions could be drawn on its basis. More likely, the "not detected" results of 0.03 to 0.06 µg/dncm are accurate and repeatable; therefore, this run was discarded. Elemental mercury is not detected in any samples, so no conclusions as to its removal can be drawn. Removal of oxidized mercury, on the other hand, is improved from 68% to 91% with the higher injection concentration.

Residual mercury emissions were extremely low (<0.5 µg/dncm) with carbon injection at either of the two rates tested in the long-term tests. Average mercury removal was 92.6% at 10 lbs/MMacf ACI and 94.7% at 20 lbs/MMacf ACI.

Figure 11 presents a summary of the parametric and long-term test results at Brayton Point. The long-term average removal efficiencies are show as large crosses. Similar to results from Gaston and Pleasant Prairie, the removal efficiency improved with long runtime.

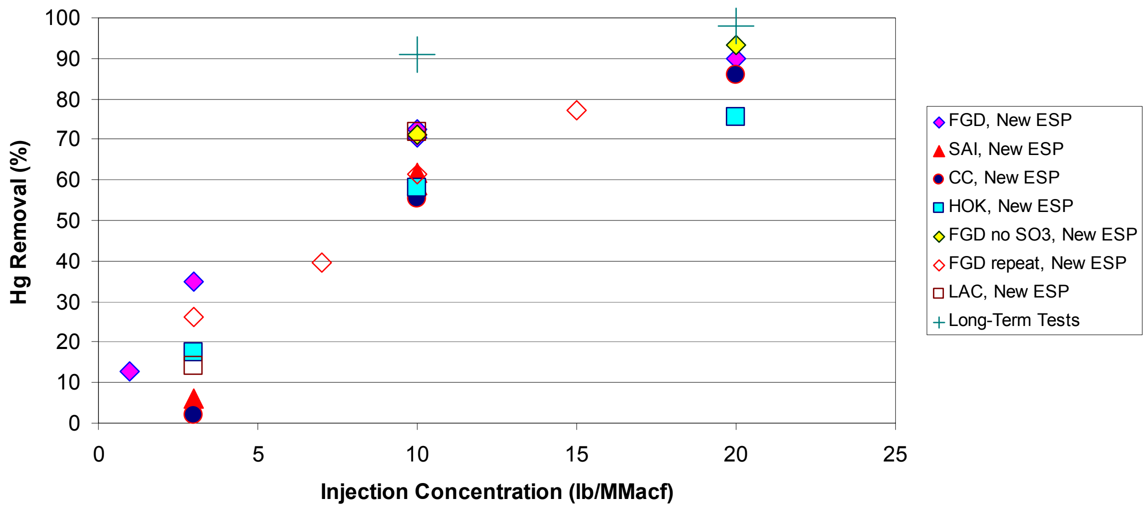

Figure 11. Mercury Removal Trends for Parametric and Long-Term Tests at Brayton Point.

Multi-Metals Test Results (Method 29)

In addition to the mercury measurements, metals emissions at the outlet of the second ESP were sampled using an EPA Method 29 sampling train. These tests were conducted at the 20 lbs/MMacf test condition. The results from metals most likely to be adsorbed by activated carbon are presented in Table 16. Results from individual test runs are provided in Appendix E.

Table 16. Method 29 Results from Brayton Point Unit 1 with Sorbent Injection (20 lbs/MMacf).

Metal	Average Concentration (µg/dscm)[1]	Emission Rate (lbs/hr)
Arsenic	0.02	1.31E-05
Chromium	1.98	1.26E-03
Lead	0.01	6.62E-06
Nickel	1.08	6.92E-04
Selenium	0.54	3.40E-04
Tin	0.49	3.10E-04

Note 1: Maximum Possible Concentrations based on detection limits.

ESP Performance

Figure 12 presents total power and carbon injection concentration for the test side of the second ESP prior to and during the long-term testing series. These data show that power levels remained at their baseline levels and there was no real change, positive or negative, when activated carbon was injected.

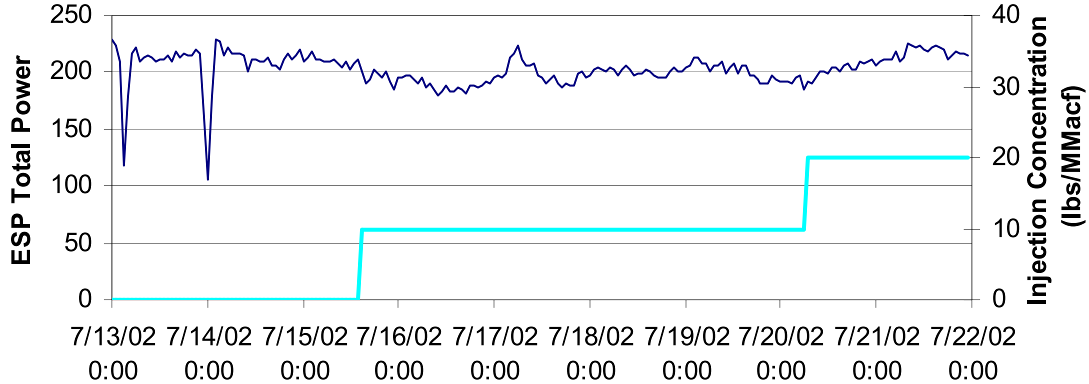

Figure 12. ESP Total Power Levels for the Test Side during Long-Term Testing Series.

COAL AND ASH CHARACTERIZATION

Reaction Engineering managed the fly ash and coal sample analyses during this program. The full report from Dr. Connie Senior of Reaction Engineering is included in Appendix F, with highlights presented here. All measurements were carried out by Microbeam Technologies, Inc.

Throughout testing, the fly ash that was collected from Unit 1 was isolated from the ash collected from other units.

Ultimate, proximate, and Hg analyses were performed on coal samples collected during testing. These measurements were used to calculate expected mercury concentrations in the flue gas for comparison with flue gas measurements.

Ash analyses performed included:

- LOI
- Mercury
- Leaching (TCLP[10] and SGLP[11])
- Chlorine
- Alkali and alkaline earth metals

Results of Coal and Ash Analyses

Coal analyses showed good comparison with the Ontario Hydro tests performed during both baseline and long-term tests. The mercury content in the baseline samples were a little lower than the samples collected during the long-term testing series. The baseline samples predicted a total gaseous mercury concentration of ~5 μg/dncm, whereas the long-term coal samples predicted a mercury concentration of 6–8 μg/dncm.

Chlorine analyses of the coal samples were high (~1,600 μg/g, dry basis) during the baseline series. The chlorine levels remained relatively high (1,300–1,600 μg/g, dry basis) during the long-term testing series although generally 10–25% lower than the baseline.

The amount of LOI in the ash during baseline conditions appeared to correlate with the mercury or chlorine contents in the ash collected in the second ESP. LOI in the ash samples varied between 4 and 6%. This correlation does not appear to be as strong in the old ESP, however it is difficult to draw conclusions from so few samples. During the baseline testing series, the LOI in the ash may have absorbed both mercury and chlorine. With these relatively high chlorine content in the flue gas, this may have contributed to the elevated mercury capture experienced during the baseline testing series.

The major conclusions from analysis of the ash are:

- Both chlorine and mercury content increased with increasing levels of LOI.
- Preliminary analysis indicates the total alkali and alkaline earth oxides contrasted with the LOI, mercury, and chlorine contents.
- During carbon injection, chlorine content on the ash collected in the second ESP significantly increased from a baseline level of ~100 μg/g to ~1,000 μg/g; in some cases, up to 2,000 μg/g.
- The amount of mercury leached from the samples during the TCLP and SGLP leaching protocols was about 100 times lower than the primary drinking water standard. There was no clear difference between the first ESP and second ESP in terms of mercury leached from the samples.

ECONOMIC ANALYSIS

After completion of testing and analysis of the data, the requirements and costs for full-scale, permanent commercial implementation of the necessary equipment for mercury control using sorbent injection technology at the 245-MW Brayton Point Station Unit 1 were determined. The cost of process equipment sized and designed based on the long-term test results for approximately 90% mercury control, and on the plant-specific requirements (sorbent storage capacity, plant arrangement, retrofit issues, winterization, controls interface, etc.) have been estimated. The system design was based on the criteria listed in Table 17.

The estimated uninstalled cost for a sorbent injection system and storage silo for the 250-MW Unit 1 is \$407,000 ± 10%. Costs were estimated based on a long-term activated carbon injection concentration of 10 lbs/MMacf. For Brayton Point Unit 1, this would require an injection rate of nominally 600 lbs/hr. Assuming a unit capacity factor of 80% and a delivered cost for PAC of \$0.50/lb, the annual sorbent cost for injecting PAC into the existing ESP would be about \$2,100,000. Additional cost information is being developed for balance-of-plant impacts.

Results from the field tests conducted to date indicate different levels of mercury removal can be achieved depending on the particulate control device and different flue gas conditions. Data collected from the field test at Gaston indicate mercury removal levels of up to 90% were obtained with COHPAC® (a baghouse). At Pleasant Prairie, 50–70% control was the maximum achievable mercury control, with the configuration of an ESP collecting PRB ash. Figure 13 presents a summary of the mercury removal trends measured at all three full-scale evaluations and the projected annual sorbent costs of PAC in $/MWh.

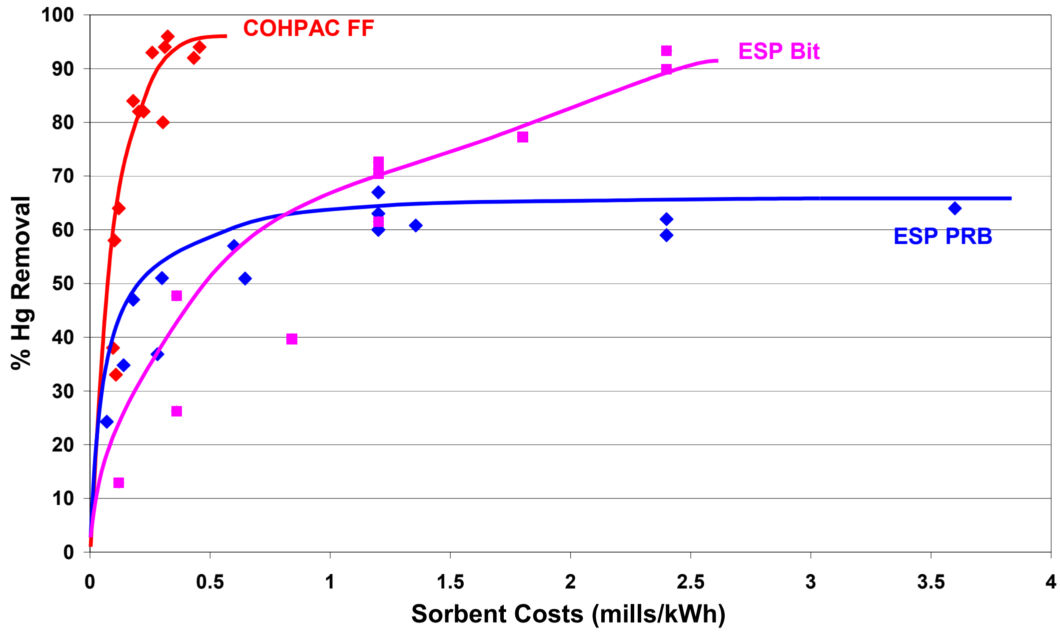

Figure 13. Comparison of Projected, Annual Sorbent Costs for an ESP and COHPAC® Fabric Filter Based on Results from NETL Full-Scale Tests, 2001–2002.

Table 17. System Design Criteria for Mercury Control System at Brayton Point Unit 1. 10 lbs/MMacf Injection, >70% Mercury Control.

Parameter	
Number of silos	1
Number of injection trains	2 operating, 1 spare
Design feed capacity/train	600
Operating feed capacity/train (lbs/hr)	300
Sorbent storage capacity (lbs)	216,000
Conveying distance (ft)	300
Sorbent	Powdered Activated Carbon
Aerated density (lbs/ft^3)	18
Settled density (lbs/ft^3)	28
Particle MMD (microns)	18

System Description

The permanent commercial Activated Carbon Injection system will consist of one bulk storage silo and three dilute phase pneumatic conveying systems. NORIT Americas provided a detailed quote for this equipment, which is included in Appendix G.

PAC sorbent will be received in 40,000 lb batches delivered by self-unloading pneumatic bulk tanker trucks. The silo is equipped with a pulse jet type bin vent filter to contain dusting during the loading process. The silo is a shop-built, dry-welded tank with three mass flow discharge cones equipped with air fluidizing pads and nozzles to promote powder flow. Point level probes and weigh cells monitor sorbent level and inventory. Silo sizing was based on the capacity to hold approximately 5.5 truckloads of PAC that would be sufficient for 15 days of operation at the design injection rate.

The PAC is fed from the discharge cones by rotary valves into feeder hoppers. From the hoppers, the PAC is metered into the conveying lines by volumetric feeders. Conveying air supplied by regenerative blowers passes through a venturi eductor, which provides suction to draw the PAC into the conveying piping and carry it to distribution manifolds, where it splits equally to multiple injection lances.

The blowers and feeder trains are contained beneath the silo within the skirted enclosure.

A programmable logic controller (PLC) is used to control all aspects of system operation. The PLC and other control components will be mounted in a NEMA 4 control panel. The control panel, motor control centers (MCCs), and disconnects will be housed in a pre-fabricated power and control building located adjacent to the silos.

Balance-of-Plant Requirements

Some modifications and upgrades to the existing plant equipment will be required to accommodate the ACI system. These include upgrades to the electrical supply at Brayton Point to provide new service to the ACI system. Instrument air, intercom phones, and area lighting will also be required.

Cost and Economic Methodology

Costs for the sorbent storage and injection equipment were provided by NORIT Americas based on the design data in Table 17. NORIT has built and installed dozens of similar systems at waste-to-energy and incineration plants. ADA-ES provided costs for the distribution manifold, piping, and injection lances. NORIT also provided an installation man-hour estimate and crane-hour estimate that were used to develop the installation costs for the NORIT equipment along with an estimate for foundations including pilings.

EPRI Technical Assessment Guide (TAG®) methodology was used to determine the indirect costs. A project contingency of 15% was used. Since the technology is relatively simple and well proven on similar scale, the process contingency was set at 5%. ACI equipment can be installed in a few months, therefore no adjustment was made for interest during construction, a significant cost factor for large construction projects lasting several years.

Operating costs include sorbent costs, electric power, operating labor, maintenance (labor and materials), and spare parts. An average incremental operating labor requirement of one hour per day was estimated to cover the incremental labor to operate and monitor the ACI system. The annual maintenance costs were based on 5% of the uninstalled equipment cost.

Levelized costs were developed based on a 20-year book life and are presented in constant dollars.

More detailed cost information in all categories, including labor rate assumptions, etc., are included in Appendix G.

Capital Costs

The uninstalled ACI storage and feed equipment costs are estimated at $407,000 ±10%. The estimated cost for a sorbent injection system and storage silo installed on 250-MW Unit 1 is $919,000 and includes all process equipment, foundations, support steel, plant modifications, utility interfaces, engineering, taxes, overhead, and contingencies. Table 18 briefly summarizes the capital and O&M costs.

Table 18. Capital and Operating & Maintenance Cost Estimate Summary for ACI System on Brayton Point Unit 1. Annual Basis 2002.

Capital Costs Summary	
Equipment, FOB Brayton Point	$407,000
Site integration (materials & labor)	$50,000
Installation (ACI silo and process	$178,000
Taxes	$33,000
Indirects/Contingencies	$268,000
Total Capital Required	**$936,000**
$/kW	**$3.74**
Operating & Maintenance Costs Summary	
Sorbent @ $.50/lb	$2,102,400
Power, labor, maintenance	$70,000
Waste disposal	$1,306,800
Annual O&M for 2003 ($/kW)	**$13.92**
Mills/kW-hr	1.99

Operating and Levelized Costs

The most significant operational cost of ACI is the PAC sorbent. Sorbent costs were estimated for nominally >70% mercury control based on the long-term PAC injection concentration of 10 lbs/MMacf. For Brayton Point Unit 1, this would require an injection rate of nominally 600 lbs/hr. Assuming a unit capacity factor of 80% and a delivered cost of $0.50/lb for PAC, the annual sorbent cost for injecting PAC into the existing second ESP would be about $2.1 Million. Other annual operating costs including electric power, operating labor, and maintenance were estimated to be approximately $70,000.

An additional cost at Brayton Point is waste disposal. With carbon injection, a certain fraction of the ash must be landfilled at an estimated cost of $250,800/yr. The rest of the ash generated from Unit 1 would be shipped to a cement kiln at an additional cost of $1,056,000/yr. The net total increase in operating cost to the plant is roughly $3.5 Million or $13.92/kW-hr.

Based on these test program results and assuming that the operation mode of ACI into the ESP is sustainable, >70% mercury control can be attained at Brayton Point Unit 1 for a capital investment of $935,467 and annual constant-dollar levelized costs of $18.15/kW. A summary of the levelized cost analysis can be seen in Table 19.

Table 19. Levelized Costs Summary.

20-Year Levelized Costs Summary – $Constant	
Fixed Costs	$109,450
Variable O&M	$4,426,826
Total	**$4,536,276**
$/kW	$18.15
mills/kW-hr	2.59

CONCLUSIONS

A full-scale evaluation of mercury control using activated carbon injection upstream of a cold-side ESP was conducted at PG&E NEG Brayton Point Station Unit 1. This comprehensive test program answered many questions about the potential for mercury control at Brayton Point, and also pointed to several areas in which more information is needed. This section summarizes the test results and conclusions.

Results and trends from these relatively short-term tests were encouraging. The overall test conclusions are:

- Activated carbon injection effectively reduced mercury in the flue gas.
- Mercury removal efficiencies >90% were seen during the long-term testing series with carbon injection concentrations of 10 and 20 lbs/MMacf.
- The high proportion of particulate-bound mercury measured at the inlet to the ESP is consistent with the high baseline removal measured at this plant. Activated carbon was shown in long-term tests to remove oxidized mercury. Elemental mercury was not detected during long-term carbon injection in any sample, so no conclusions can be drawn as to its removal.
- The presence of SO_3 in the flue gas from the EPRICON flue gas conditioning system did not affect performance of the activated carbon in terms of mercury capture.
- No detrimental impacts on ESP performance were observed as indicated by total power levels and stack opacity.
- The performances of different activated carbons were relatively similar at the higher injection concentrations. During the lower injection concentrations, mercury captured varied among the different sorbents. Additional testing needs to be conducted to fully document the performance variability between the alternate sorbents.
- The cost to obtain consistent mercury removal of 90% at Brayton Point (using 10 lbs/MMacf PAC injection into the ESP) with the current PCD configuration is estimated at $2,100,000/yr.

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APPENDIX A

TEST PLAN

DOE NATIONAL ENERGY TECHNOLOGY LABORATORY MERCURY FIELD EVALUATION

PG&E NEG Brayton Point Power Plant
Sorbent Injection into Cold-Side ESP for Mercury Control

Test Plan Prepared for:
PG&E NEG
DOE NETL
EPRI

Test Plan Prepared by:
ADA-ES

April 16, 2002

PROJECT OBJECTIVES

The overall objective of this project is to determine the cost and impacts of sorbent injection into the cold side ESP for mercury control at PG&E NEG Brayton Point Power Plant Unit 1. Impacts that will be evaluated include ESP performance and ash marketability. The evaluation will be conducted on ½ of the Unit 1 gas stream, nominally 125 MW.

PROJECT OVERVIEW

This test is part of an overall program funded by the Department of Energy's National Energy Technology Laboratory (NETL) to obtain the necessary information to assess the costs of controlling mercury from coal-fired utility plants. The economics will be developed based on various levels of mercury control at four different host sites. The four sites, shown below, burn coal and have particulate control equipment that are representative of 75% of the U.S. coal-fired generation.

Test Site	Coal	Particulate Control
PG&E NEG Salem Harbor	Low S. Bituminous	Cold Side ESP
PG&E NEG Brayton Point	Low S. Bituminous	Cold Side ESP
Wisconsin Electric Pleasant Prairie	PRB	Cold Side ESP
Alabama Power Gaston	Low S. Bituminous	Hot Side ESP COHPAC FF

Brayton Point Unit 1 was chosen for this evaluation because of its combination of firing Low Sulfur Bituminous coal with a cold-side ESP. This combination covers a wide range of coal-fired power plants operating in the eastern part of the U.S. It also provides unique challenges that must be evaluated to determine the true impacts of carbon injection. Operating conditions will be modified to optimize the performance in terms of both mercury capture and emissions compliance in short-term tests, followed by longer-term tests that will more thoroughly evaluate the operational impacts and costs at reasonable injection rates.

Brayton Point has unique conditions that are important to this program. They include:

1. PG&E NEG is currently evaluating mercury control options to meet new state compliance regulations in 2006. Sorbent injection is one of the viable options for mercury control.

2. The new ESP (Research-Cottrell) chamber can be treated in isolation, and long duct runs provide good residence times to maximize performance of sorbent injection.

3. Use of the existing STI separator to produce a high carbon flyash, which can be tested as a sorbent at Brayton Point.

4. Brayton Point has a unique configuration of two ESP's in series. Since sorbent will be injected upstream of the second ESP where >90% of the flyash is already removed, it should be easier to document the impact of sorbent injection on ESP performance.

General Technical Approach

Testing at Brayton Point is part of a field evaluation program that will implement sorbent injection mercury control technology on portions of full-scale particulate control equipment to obtain performance and operational data, and gather samples to determine the impact of the sorbents on waste disposal and byproduct reuse.

A series of parametric tests is conducted to determine the optimum operating conditions for several levels of mercury control. The maximum injection rate will be set based on practical limitations of ESP performance, ash impacts, and cost. Based on results from these tests, a two-week test with activated carbon and optimized conditions will be conducted to assess longer-term impact to ESP, ash and auxiliary equipment operation. To save costs during optimization, mercury levels will be measured with a semi-continuous emissions monitor (S-CEM). During the long-term test The S-CEM and mercury removal efficiencies will be verified by draft Ontario Hydro method measurements.

At each site, at least two sorbents will be evaluated during the parametric tests. A standard activated carbon, a lignite-derived activated carbon, supplied by Norit Americas Inc., and to-be-determined alternate sorbents that offer advantages in performance, price, or impact on waste issues.

The economic analysis will include:

Capital costs	Waste disposal issues
Sorbent usage costs	Byproduct utilization issues
Impact on ESP operation	Enhancements, such as cooling
Balance of plant	O&M requirements

At Brayton Point, final sorbent selection for the parametric tests will be determined by sorbent screening tests. These field tests measure mercury absorption capacity and provide a good indication of how the sorbent will perform. Given the large quantity of sorbent required for the long-term tests, it is necessary to select the sorbent well in advance to have the amount on hand.

Injection equipment will be installed in April of 2002. Injection Equipment will be installed and fully operational by May 31, 2002. Testing will be conducted during the summer of 2002.

SITE DESCRIPTION

PG&E National Energy Group owns and operates Brayton Point Station located in Somerset, Massachusetts. There are four fossil fuel fired units at the facility designated as Units 1, 2, 3, and 4. In 1982, three of the four units, (Units 1, 2, and 3) were converted from oil to coal. The units fire a low sulfur, bituminous coal. Unit 1, which is scheduled to be the test unit, has a tangentially fired boiler rated at 245 net MW.

The primary particulate control equipment consists of two cold-side ESP's in series, with an EPRICON flue gas conditioning system that provides SO_3 for fly ash resistivity control. The EPRICON system is not used continuously, but on an as-needed basis. The first ESP (Old ESP) in this particular configuration was designed and manufactured by Koppers. The Koppers ESP has a weighted wire design and a specific collection area (SCA) of 156 ft^2/1000 acfm. The second ESP (New ESP) in the series configuration was designed and manufactured by Research-Cottrell. The second ESP has a rigid electrode design and an SCA of 403 ft^2/1000 acfm. Total SCA for the unit is 559 ft^2/1000 acfm. The precipitator inlet gas temperature is nominally about 280°F at full load.

The first precipitator consists of four parallel chambers each with 28 gas passages 24' long at 10" centers. Each chamber is further divided into three collecting surface fields. The first ESP has a total of 12 T/R sets.

The second precipitator consists of two parallel chambers. Each chamber is subdivided into 38 gas passages 54' long at 12" centers. The chambers are then divided into six collecting surface fields. The second ESP contains a total of 24 T/R sets.

Hopper ash is combined between both precipitators in the dry ash-pull system. The ash is processed by an on-site STI carbon separation system, to reduce the carbon content to approximately 2%. This processed ash is sold as base for concrete and is considered a valuable product for the Brayton Point Station. The remainder of the higher carbon ash is a disposable waste. One precipitator's ash can be isolated from the balance of the unit, however this is a labor intensive procedure.

A summary of important descriptive parameters for Brayton Point Unit 1 is presented in Table 1.

Table 1
Site Description Summary, Brayton Point Unit 1

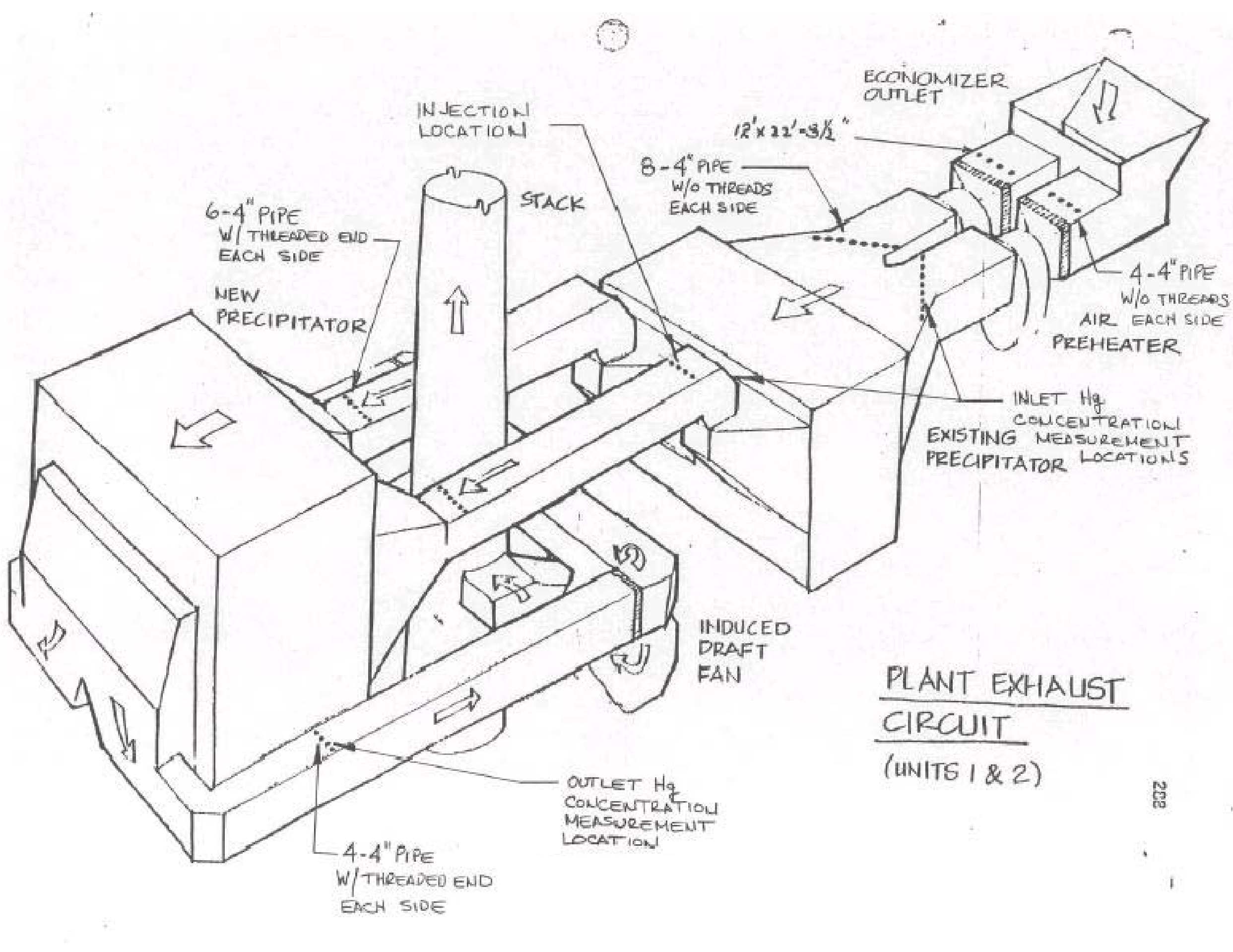
PARAMETER IDENTIFICATION	DESCRIPTION
Process	
Boiler Manufacturer	C-E tangential, twin furnace
Burner Type	C-E LNCFS III (32 burners)
Low NOx Burners	Yes
Steam Coils	Yes
Over Fire Air	Yes
NOx Control (Post Combustion)	None
Temperature (APH Outlet)	280^{o}F
Coal	
Type	Eastern Bituminous
Heating Value (Btu/lb)	12,319
Moisture (%)	6.6
Sulfur (%)	0.72
Ash (%)	11.32
Hg (µg/g)	0.05
Cl (%)	0.08
Control Device	
Type	Cold-Side ESPs in series
ESP #1 Manufacturer	Koppers
Design	Weighted Wire
Specific Collection Area (ft^2/1000afcm)	156
ESP #2 Manufacturer	Research Cottrell
Design	Rigid Electrode
Specific Collection Area (ft^2/1000afcm)	403
Flue Gas Conditioning	SO_3 Injection, EPRICON

TECHNICAL APPROACH

Sorbent for mercury control will be injected into the ductwork in between the two electrostatic precipitators. Only one of the two inlet precipitator ducts will be treated, nominally 122 MW. This meets DOE's requirement to evaluate units up to 150 MW. This particular ESP configuration will allow us to measure in-flight mercury removal efficiency between the two ESP's and mercury removal efficiency across each ESP.

Figure 1 presents a diagram of the particulate control equipment at Brayton Point. This figure shows that each unit has two ESP's in series.

Figure 1: Isometric View of the ESP arrangement at Brayton Point (Unit 1)



The primary objective of the field evaluation at Brayton Point will be achieved through eight technical tasks. In the overall program these tasks are numbered 2 through 9. The tasks are identified in the following flow chart.

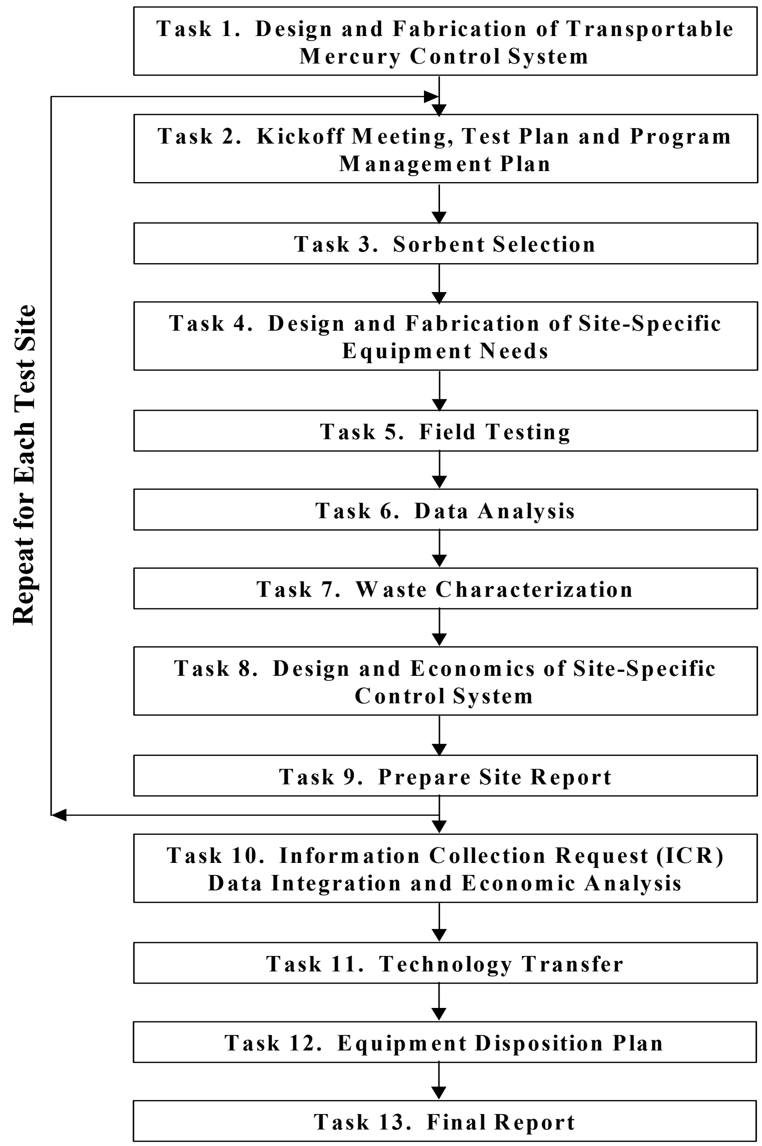


Figure 2 presents a tentative schedule for the field test portion of the Brayton Point program. Figure 2 also shows that field testing should be completed in Summer of 2002.

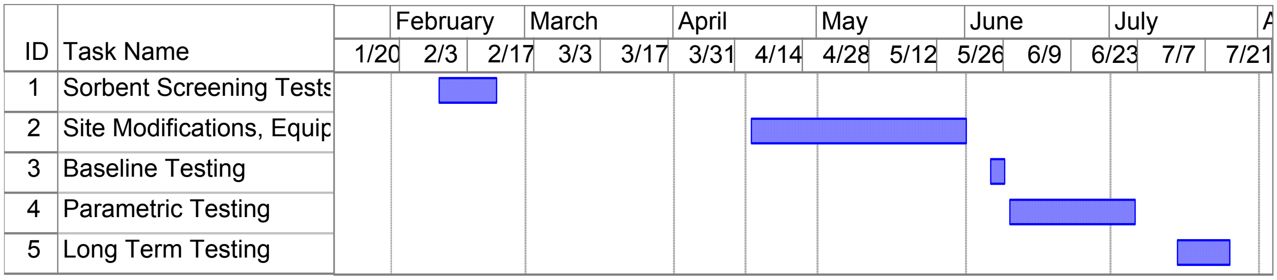


Figure 2. Test Schedule for Brayton Point Unit 1

Task 2 – Kickoff Meeting and Test Matrix

A kickoff meeting was held January 9, 2002 with appropriate plant, project and environmental personnel. At this meeting the overall scope of the program, the potential impact on plant equipment and operation, environmental permitting issues and site-specific goals were discussed.

This document provides detailed breakdown of the test matrix including the expected settings for the parametric tests, a list of samples and test procedures, a task schedule and sampling QA protocol. The detailed test results from Sorbent Screening tests are also included in this Test Plan.

Task 3 – Sorbent Selection

The test schedule was extended to allow for the evaluation of six sorbents. The benchmark sorbent that has been tested in many research and pilot-scale programs to date is a lignite-derived activated carbon referred to as Darco FGD carbon. The sorbents for Brayton Point parametric testing were selected based on test results in laboratory and slipstream. Selected sorbents are identified in section 5.2.

Sorbent selection criteria were developed so that sorbent vendors/developers clearly understand the needs and requirements of this program. In summary an alternative sorbent must:

1. Be less expensive than FGD carbon;
2. Be available in quantities of at least 15,000 lbs;
3. Show that this sorbent will be available in sufficient quantities to supply at least 100 tons per year by 2007;
4. Have a capacity of at least 100 μg/g as measured in the laboratory by URS Corporation (not applicable to STI processed ash).

A summary of other sorbents that were evaluated in laboratory and slipstream testing is included in the Sorbent Screening Summary (separate document).

Subtasks 3.1 & 3.2 – Activated Carbon and Site-Specific Sorbent Screening

Sorbents being considered for the full-scale evaluation were tested for adsorption capacity on a slip stream of flue gas using a fixed bed device. The fixed-bed sampler can determine the mercury adsorption capacity of a dry sorbent at controlled-temperature conditions. The sampler can be located upstream or downstream of SO_3 injection. These two variables, temperature and SO_3 injection, are of interest for different reasons. Tests indicate that mercury removal may involve both physical- and chemical- adsorption mechanisms. Mercury adsorption decreases as the reaction temperature increases, typical of physical adsorption. The presence of SO_3 in the flue gas, decreases the adsorption capacity of the sorbent. However, if the sorbent maintains an adsorption capacity above a certain threshold, its ability to capture mercury is not affected.

On February 11, 2002 Carl Richardson of the URS Corporation, conducted the sorbent screening tests at Brayton Point Unit 1. During these tests, approximately 14 different sorbents were analyzed measuring their mercury adsorption capacity. Results indicated the presence of SO_3 in the flue gas from the EPRICON system, decreased the adsorption capacity of a few sorbents by a factor of at least 2.

Results from these screening tests have been evaluated by the PG&E NEG mercury project team and five alternative sorbents were chosen for the full-scale field test at Brayton Point. These sorbents were chosen based upon the selection criteria described above.

Task 4 – Design and Fabrication of Site-Specific Equipment Needs

The mercury control process equipment has been fabricated and delivered to the Brayton Point Station. The objective is to have the equipment fully installed and operational by May 6, 2002.

Sorbent Injection System

The transportable sorbent injection system consists of a bulk-storage silo and twin blower/feeder trains each rated at 750 lb/hr. Sorbents will be delivered in bulk pneumatic trucks and loaded into the silo, which is equipped with a bin vent bag filter. From the two discharge legs of the silo, the reagent is metered by variable speed screw feeders into eductors that provide the motive force to carry the reagent to the injection point. Regenerative blowers provide the conveying air. A PLC system is used to control system operation and adjust injection rates.

Flexible hoses will carry the reagent from the feeders to distribution manifolds that are located on the second ESP inlet duct, feeding the injection probes. Each manifold will supply 4 to 6 injectors. The number and position of the injectors will be determined through system shake down and optimization tests.

ADA-ES will work with the station and its installation subcontractors to provide all required information for system installation and operation. ADA-ES has provided a drawing package of the ADA-ES supplied equipment and installation requirements as well as criteria and specifications for Balance of Plant (BOP) equipment and materials provided by others. ADA-ES has also provided a final list of utility requirements (electric power, water, compressed air) for the injection system.

The sorbent injection silo/feeder system, designed and supplied by Norit, is described below:

- 2500 ft^3 storage silo with twin discharge
- Bin vent bag filter
- Level switches and radar type level transmitter
- Two rotary valves
- Two feeder hoppers
- Two volumetric feeders
- Two Pneumatic blower and eductor trains
- Load cells
- Pressure switches
- NEMA 4/4x design
- PLC system control panel
- Safety and trip interlocks
- Electrical requirement: 480V/3ϕ/60Hz : 80 Amps
- Compressed air requirement: 8 scfm @ 30 psig of instrument-quality air (intermittent use)

Responsibility for procurement of the sorbent injection system is divided between ADA-ES and PG&E as shown in Table 4.

Table 4. Scope Split for Sorbent Injection System

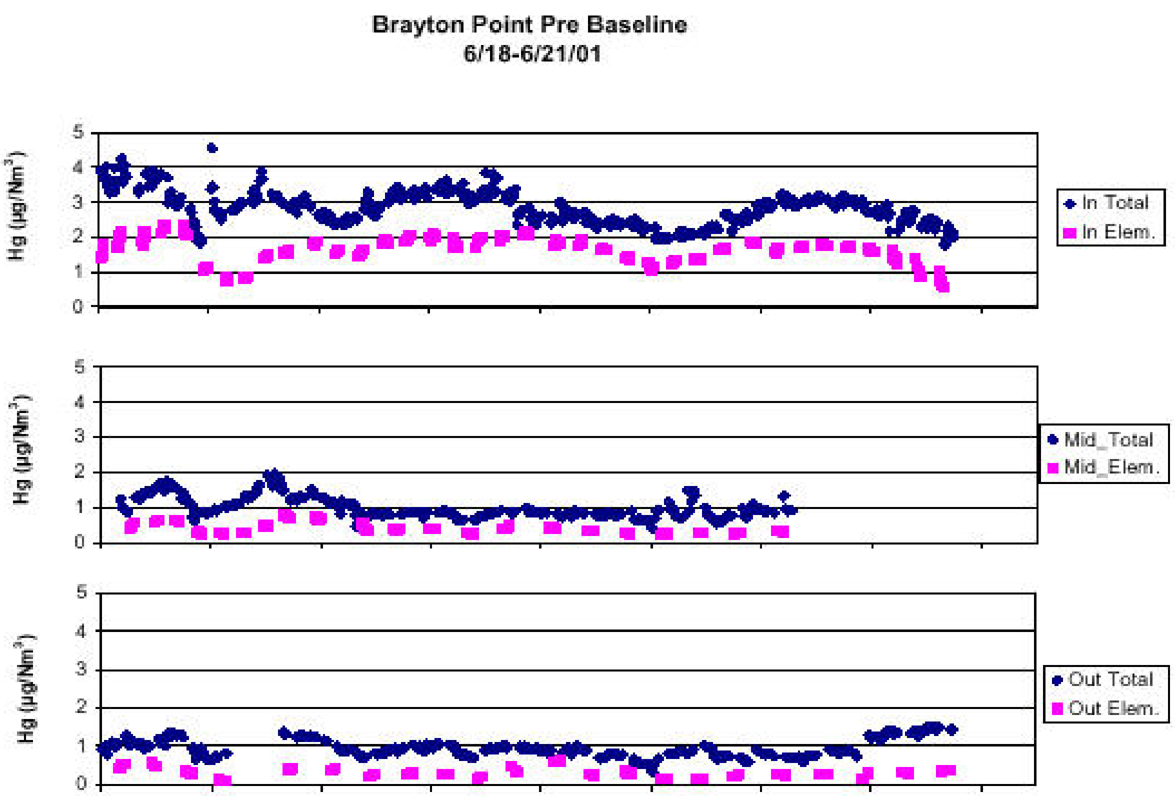
ADA-ES Transportable System	Provided by Host Site
Silo/Feeder System	Injection ports
Sorbent Distribution Manifolds	Test ports
Conveying Hose (400 ft)	Access platforms
Sorbent Injectors	Installation labor/Materials
PLC Controls, HMI and Programming	Compressed air
Hg SCEMs	480V Power
Office Trailer	Signal Wiring

Task 5 – Field Testing

The field tests will be accomplished through a series of nine (9) subtasks. The subtasks are independent from each other in that they each have specific goals and tests associated with them. However, they are also interdependent with the results from each task influencing the test parameters of subsequent tasks.

Subtask 5.1 – Pre-Baseline Measurements

These tests were conducted June 14-22, 2001 at Brayton Point Station on Unit #1. Using a vapor phase mercury Semi-Continuous Emissions Monitor (S-CEM) supplied by Apogee Scientific, mercury measurements were taken at three different locations. Results indicated that a majority of the mercury was captured across the first ESP. These results were documented in a memo issued on 6/22/01, and are summarized in the graphs below.



Subtask 5.2 – Sorbent Screening

Sorbent screening was conducted on a slipstream of flue gas from Unit 1. Table 6 summarizes the actual test results from the screening.

Norit FGD showed a relatively high adsorption capacity, and has been selected for full-scale testing. In addition to its high adsorption capacity, it has been the sorbent used for the pilot scale and research tests. It has also been tested in the previous two full-scale demonstrations at Alabama Power; Plant Gaston and WE-WG; Pleasant Prairie Power Plant. Field data collected from Brayton Point will be compared to the previous demonstrations, and help determine how the different plant characteristics affect the sorbents ability to capture mercury.

Donau HOK300 also showed a relatively high adsorption capacity. This sorbent is manufactured in Germany and has a D50 of approximately 18 microns. In addition to it's high adsorption capacity, Donau offers very competitive pricing for the demonstration at Brayton Point. This sorbent is used in Municipal Solid Waste Incinerators across Europe to collect different pollutants, primarily for mercury capture. Donau HOK300 has met the sorbent screening criteria and is recommended for testing full-scale at the Brayton Point power plant in June 2002.

CarboChem supplied a product to be tested during the sorbent screening. This particular activated carbon is manufactured from a bituminous coal and showed an adsorption capacity > 100 μg/g. CarboChem, a privately held corporation based in Philadelphia, provides industrial chemicals around the world with a special emphasis on activated carbon. It also has favorable pricing and is recommended for testing full-scale during the parametric testing series.

Superior Adsorbents, Inc. also provided an activated carbon. Superior Adsorbents' activated carbon product showed an extremely high adsorption capacity with the presence of SO_3 in the flue gas stream. In addition to its high adsorption capacity it has competitive pricing and is recommended for full-scale testing at Brayton Point power plant in June 2002.

Advanced Fuel Research (AFR) supplied a product to be tested in the sorbent screening. This tire-derived product is manufactured locally and like the Donau has very competitive pricing. This alternate sorbent allows the Brayton Point mercury project team to test a locally produced sorbent, rather than an activated carbon from a large manufacturer. Along with the Norit and Donau activated carbons, these three sorbents are the only activated carbons recommended for testing during the full-scale demonstration at Brayton Point.

The final sorbent being tested at Brayton Point will be the processed flyash from the STI system. The flyash from the STI system will be processed until 80% of the sorbent is carbon. The adsorption capacities were not as high compared to the activated carbons, but this would allow the project team to test an alternate sorbent other than activated carbon.

A summary of the test results from February 2002 is presented in Table 6. General observations include:

- The Norit carbons displayed very high adsorption capacities;
- DonauHOK300 displayed a very high adsorption capacity;
- The presence of SO_3 from flue gas conditioning inhibited adsorption, in some cases it reduced the adsorption capacities of some products by a factor of 6;
- The STI products showed some promise, however adsorption capacities are reduced to zero with the presence of SO_3 in the flue gas

Table 6

Results from Sorbent Screening Tests Conducted by URS Corporation (February 2002)

Sample Name	Base	Ads. Capacity SO_3 Off @ 50 mg/Nm^3	Ads. Capacity SO_3 On @ 50 mg/Nm^3
Norit FGD	Lignite	4314	1380
Norit FGL	Lignite	4281	694
Donau GAL	Lignite	-	1745
Donau HOK300	Lignite	4786	-
Advanced Fuel Research – 2	Tire Derived	-	538
CarboChem	Bituminous	1948	-
SAI-B	Bituminous	1799	-
SorbTech-I	?	62	-
SorbTech-L	Lignite	2091	-
STI 020115-2	BP ash, 80% carbon	>109	0
STI 020121-3	SH ash, 80% carbon	245	0
AANP Zeolite	-	-	7

Subtask 5.3 – Site Modifications, Equipment Installation and System Checkout

ADA-ES will oversee installation and checkout of the mercury control equipment. The mercury control process equipment has been fabricated and has been delivered to the Brayton Point Station. The objective is to have the equipment fully installed and operational by May 31, 2002.

The plant and its installation subcontractors will install the equipment including any forklift or crane support. This will include anchoring of the injection skid, running and supporting the flex hose, mounting the injection manifold, providing and terminating electric power and compressed air to the injection skid.

Fly ash from both ESPs are combined in the ash pull system and sold. To assure that sorbents that are used for mercury capture do not contaminate the balance of ash, fly ash from both ESPs on Unit 1 will be isolated from the rest of the system. This will eliminate the possibility of contaminating the ash produced from the other units at Brayton Point.

Samples will be collected during system checkout and TCLP and concrete tests will be conducted before any ash is combined. The plan is to isolate the test ESP hoppers while the sorbent injection system is operated at maximum feedrate. Ash will not be blended with the balance of plant ash while analyses of the samples are being conducted. If a problem is identified, this same procedure will be used to isolate ash during testing.

Subtask 5.4 – QA/QC Plan

Subcontractors will be performing the various sampling and analytical functions required to evaluate the effectiveness of the mercury controls. All testing personnel will be required to adhere to written QA/QC procedures. QA/QC procedures will be prepared as part of detailed test matrices that will be submitted ahead of testing dates for approvals by PG&E NEG, DOE and EPA. The plans will include the necessary QA/QC activities that are required to assure the validity of collected data. At a minimum, the QA/QC Plan will include a description of the test methods to be used; instrument/equipment testing, maintenance and inspection procedures; instrument calibration and frequency; inspection/acceptance requirements for supplies and consumables; procedures for checking data reduction and validation; and sample handling and chain of custody requirements. Standard methodologies and procedures have been established for all the methods to be used in the testing, therefore no new or unproved techniques will be introduced to the project.

Subtask 5.5 – Baseline Testing

An overview of the planned full-scale tests is shown in Table 7. The various tests are described below in their corresponding Subtask.

Table 7
Full-Scale Test Sequence for Brayton Point

Test Description	Dates	Parameters/Comments	Boiler Load
Baseline tests (No injection)	June 5 - 8	Day 1 – Ontario Hydro Tests Day 2 – Ontario Hydro Tests Day 3 – Ontario Hydro Tests Day 4 – Increase residence time in duct Operate at low load[1], no carbon injection (*Perform test condition on Saturday, June 8, 2002*)	Full Load – 24 hours a day during Ontario Hydro Tests [1] Low Load – 06:00-20:00
Parametric Week 1 (Baseline Hg Capture WRT Operational Changes and Carbon Injection – FGD)	June 10-14	Day 1 – Load Silo with Norit FGD,Detune ESP[3] (Reduce power section by section) Operate at Full load *, no carbon injection Day 2 –co-current/counter-current injection, injection concentration TBD (Operate at Full Load) * Day 3 – multiple nozzle lance injection (Operate at Full Load) * Day 4 – Inject at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Inject at 3 lbs/Mmacf (0.08 lbs/Mmbtu) (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week2 (Carbon Injection – FGD, SAI, CC)	June 17-21	Day 1 – Inject at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 2- Load Silo w/ SAI, inject at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Inject SAI at 10 lbs/Mmacf (0.25 lbs/Mmbtu), feed out sorbent(Operate at Full Load) * Day 4 – Load silo w/ CC, Inject CC at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Inject CC 10 lbs/Mmacf (0.25 lbs/Mmbtu), Feed out sorbent (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week 3 (Carbon Injection – Donau, FGL, STI)	June 24-28	Day 1 – Load Silo w/ Donau, Inject AS#3 at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 2 – Inject Donau at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Load Silo w/ FGL, Inject FGL at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 4 – Inject FGL at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Load Silo w/ STI, Inject STI at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week 4 (Carbon Injection –STI, FGD)	July 1-5	Day 1 – Inject STI at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 2 – Load silo/ with Norit FGD, Detune ESP[3] (Reduce power section by section), injection concentration TBD (Operate at Full Load) * Day 3 – SO_3 Conditioning on, Injection concentration TBD (Operate at Full Load) * Day 4 – Contingency Day 5 – Contingency	* Full Load – 06:00-20:00
Parametric Week 5	July 8-12	Day 1-5 – Contingency	
Long Term Test (Carbon Injection – Norit FGD)	July 15 – 25	Sorbent – Norit FGD, injection concentration TBD July 22 – OH (Operate at Full Load) * July 23 – OH (Operate at Full Load) * July 24 – OH (Operate at Full Load) *	* Full Load – July 22-24 (24 Hours a day)

[1] - *Low Load times are subject to change*
[2] - *Activity subject to MASS DEP Approval*
* - *Injection concentrations are subject to change depending on preliminary parametric test results*

After equipment installation, baseline tests are scheduled to occur immediately prior to the first parametric test series to best document baseline conditions. During this test it is requested that boiler load will be held steady at “full-load” conditions 24 hours per day. Mercury across the selected ESP chamber will be measured using two separate methods:

1) the S-CEM; and
2) standard Ontario Hydro Testing.

A description of the mercury S-CEM can be found in Appendix C.

The Ontario Hydro tests will be conducted by TRC Environmental Corporation. TRC Environmental Corporation will prepare a detailed test plan, complete with QA/QC procedures, prior to testing.

Performance of the ESP is critical to the success of sorbent injection for mercury control. Boiler (Unit 1) operation is important in order to determine that the tests are conducted under obtainable, sustainable operating conditions. The main operating indicators of interest are described here and listed in Tables 8 & 9.

ESP Performance

Electrical Parameters: Primary and secondary voltage and current, as well as spark rate, will be monitored using existing instrumentation to document any changes in ESP power characteristics.

Flue Gas Temperature: Recorded from plant instrumentation and during any manual traverses.

Rapping Pattern: Any change to the rapping pattern that is required for good performance will be recorded and evaluated.

SO_3 Injection: During normal operating conditions, the EPRICON flue gas conditioning system is off. However, during some testing conditions, it will be required that this system be on. This particular testing condition will be coordinated in advance with the plant.

Opacity/Emissions: Ash resistivity, electrical characteristics, and rapping affect collection efficiency across the ESP. We have calculated that it is not expected emissions will increase with this series of tests, however emissions will be documented by both manual measurements and the site’s opacity monitor. Particulate measurements following EPA Test Method 5 will be conducted in conjunction with the Ontario Hydro measurements.

Coal, Ash and Flue Gas Samples

Ash Samples: Fly ash hopper samples will be taken from the ESP hoppers. These ash samples will be analyzed for mercury to compare to in-situ measurements. It is anticipated that samples will be taken during each test condition. Other analyses such as carbon content and composition will be conducted as needed.

Coal Samples: Coal samples will be collected daily. These samples will be analyzed for mercury.

Flue Gas Samples: A CAMRAC online LOI analyzer will be used to determine the amount of LOI carbon in the flue gas. This instrument will be placed on the economizer outlet duct upstream of the air preheater. Data will be collected and analyzed daily.

Unit 1 Operation

System Operation: Boiler load, stack opacity, other stack CEM measurements, flue gas temperatures before and after the ESP, coal source and documentation of operation that may affect the combustion process such as pulverizers that may not be working, etc.

Table 8 presents data to be collected during baseline, parametric and long term testing. These data will be used to evaluate sorbent injection performance.

Table 8
Test Data Collected from Sorbent Injection Chamber During Evaluation

PARAMETER	SAMPLE/SIGNAL/TEST	BASELINE	PARAMETRIC/ LONG-TERM
Coal	Batch sample	Yes	Yes
Coal	Plant signals: burn rate (lb/hr) quality (lb/MMBTU, % ash)	Yes	Yes
Fly ash	Batch sample	Yes	Yes
pH of ESP ash	Batch sample	Yes	Yes
Unit operation	Plant Signals: Boiler load Flow rates and temperatures	Yes	Yes
Temperature	Plant signal at inlet and outlet of ESP	Yes	Yes
Temperature	Full traverse, inlet & outlet	Yes	No/Yes
Duct Gas Velocity	Full traverse, inlet & outlet	Yes	No/Yes
Mercury (total and speciated)	Inlet to new ESP, inlet and outlet of old ESP with S-CEM	Yes	No
Mercury (total and speciated)	Ontario Hydro, inlet and outlet	Yes (1 set)	No/Yes (1 set)
Sorbent Injection Rate	PLC, lbs/min	No	Yes
CEM data (NO_x, O_2, SO_2)	Plant data – stack	Yes	Yes
LOI	LOI monitor, inlet to air preheater	Yes	Yes
Stack Opacity	Plant data	Yes	Yes
SO_3	Plant chart/catalyst temperature and flow	Yes	Yes
ESP operation	Plant data (ESP electrical, rapping, etc.)	Yes	Yes

Subtask 5.6 – Parametric Test Series 1 & 2: Mercury Removal versus injection rate and distribution patterns as well as plant operational changes.

The parametric test series is divided into three primary areas of interest:

Mercury removal as a function of injection rate;
The affect of operational conditions, with and without carbon injection on mercury removal; and
Alternative sorbents to Norit FGD.

Operating the unit at low load, thus reducing flow, will increase mercury residence time upstream of the ESP. Although this approach will also change other variables, we hope to determine the effect residence time has on mercury removal across the system. This will be the first condition tested prior to carbon injection.

The effect of plant operation will be evaluated with and without carbon injection. Variables of interest include residence time and particulate loading into the second ESP.

Deenergizing the first ESP will provide information that would help determine if changes in performance of the first ESP impact mercury capture in the system. Specifically, this will increase the particulate loading to the new ESP and perhaps increase mercury removal because of longer exposure of ash to vapor phase mercury in the flue gas. This could help explain variable collection efficiency at different test times.

The first test with carbon injection will be to optimize the injection lance design and carbon distribution in the flue gas. Two sets of lances are being fabricated. The first design uses 1-inch pipe with a single nozzle at the bottom of the pipe. Two pipes, two nozzles, will be installed in each of the four ports. The length of each injection lance has not been finalized. The second design uses a single 1-inch pipe with multiple nozzle openings drilled along the length of the pipe. This design is also being finalized. Different injection spray patterns may result in better distribution, thus enhancing mercury removal. Once the distribution pattern is optimized, the remaining parametric tests and long term tests will use that injection configuration.

The set of parametric tests will be to document mercury removal for three sorbent injection rates conducted at full-load conditions. The sorbent for these tests will be Norit's Darco FGD. The maximum injection rate predicted will be 10 lbs/Mmacf (.25 lbs/Mmbtu). Previous full scale testing showed that increasing the injection concentration of sorbent had no impact on additional mercury removal. The removal rates will be checked with feedback from the S-CEM. Two lower rates than maximum will be tested in order to trend injection rates with removal efficiencies. Operating and performance parameters to be monitored during this test are documented in Table 8.

The final week of parametric testing will be to determine what effect the presence of SO_3 has on the sorbents' ability to capture mercury. During this particular testing condition, the EPRICON flue gas conditioning system will be in service. This effort will be coordinated with the plant prior to test.

DOE may provide (or coordinate with PG&E NEG) for additional sampling during the parametric testing. DOE would primarily be concerned with co-pollutant control measurements of SO_3, HF, NO_x, HCl, multi-metals and fine particulate matter.

Subtask 5.7 – Parametric Test Series 3: Mercury Removal with Alternate Sorbents and

In addition to the plant operational changes and different injection concentrations, the mercury project team will be testing five alternate sorbents and their ability to capture mercury. In addition to the Norit FGD two alternate sorbents will be tested during the second week of parametric testing. The following week of parametric testing, the project team will be testing three additional alternate sorbents. Each alternate sorbent will be tested at two different injection concentrations, 3 lb/Mmacf (0.08 lbs/Mmbtu) and 10 lbs/Mmacf (.25 lbs/Mmbtu). These two data points will be compared to the benchmark sorbent, Norit's FGD.

After these tests the test crew will leave the site to analyze data and work with team members on establishing conditions for the long term test. One week is scheduled between subtask 5.7 and the long term tests, subtask 5.8.

Subtask 5.8 – Long Term Testing

Mercury removal validation testing will be conducted for a maximum of ten days at the "optimum" plant operating conditions and sorbent injection concentration (highest mercury removal at practical cost) as determined from the parametric tests. The sorbent used will be the Benchmark Activated Carbon, since this is the only sorbent that can feasibly be obtained in time and in the large quantity needed for these tests. The project team will obtain concurrence from DOE and PG&E on the test conditions and length of testing. The S-CEM will be used for continuous monitoring of mercury removal. Ontario Hydro measurements at the inlet and outlet will be conducted periodically. A summary of the parameters to be monitored during this test is presented in Table 8. A preliminary report shall be prepared documenting the removal efficiency over time, the effects on the ESP and balance of plant equipment, and operation of the injection equipment to determine the viability and economics of the process.

Task 6 – Data Analysis

Data collected during the field evaluation will be used to prepare a summary report on the effect of sorbent injection on mercury control and the impact on existing pollution control equipment. Various plant signals will be monitored to determine if any correlation exists between changes in mercury concentration and measured plant operating conditions. This analysis will include a characterization of mercury levels and plant operation for baseline conditions, various injection rates, various temperatures (if determined appropriate), and two sorbents. This analysis will also identify effects of sorbent injection on operation and predict long term impacts.

Coal and fly ash samples will be collected during baseline and long term tests for analysis. Ultimate and proximate analysis and measurements for mercury, chlorine and sulfur of the coal will be conducted. Ash samples will be analyzed for mercury and carbon content. Ash samples will also be analyzed by hopper section to determine if there is mercury segregation across the ESP. Task 7 describes further analyses.

A full temperature, velocity, particulate loading and mercury (total and speciated) traverse at the inlet and outlet at full load conditions will be conducted to determine profiles for appropriate sampling and sorbent distribution. The S-CEMs will be placed at a location with average velocity for sampling.

Task 7 – Waste Characterization

The standard testing technique used for assessing hazardous waste characteristics is the Toxicity Characteristic Leaching Procedure (TCLP, SW846-1311). The test protocol involves exposing a 100-gram sample of ash to 1-liter of acidic solution (acetic acid-or acetate based) for 24 hours. The solution is then analyzed for several metals (including mercury) to determine how much of each target metal was leached from the solid sample. Results are compared against limits established by regulation. In the case of mercury, a maximum leachable level of 0.2 mg/liter has been established. (Note: in most cases the TCLP limits for mercury cannot be exceeded even if all the mercury leaches. These tests will be performed to establish a record of the wastes generated during the program.)

A second series of tests will be performed to answer the question of the stability of the mercury. The potential long-term environmental impact of the mercury-laden ash will be determined using a leaching method known as the synthetic groundwater leaching procedure (SGLP) (Hassett, et al. These tests will be conducted by the Microbeam Technologies Inc. This test is modeled after the TCLP, but modified to allow for disposal scenarios. A shake extraction technique is used to mix the solid sample with an aqueous solution. Aliquots of the liquid are then analyzed after 18 hours, 2 weeks, and 4 weeks.

Another set of analytical tests will be performed to evaluate whether the waste ash is suitable for use in concrete formulations. Tests are conducted to evaluate properties under ASTM Specification C618, which include chemical and physical property analysis. Air entrainment shaker tests will also be performed as part of the concrete suitability test series.

Sampling and QA/QC procedures will be documented in the test plan as described in Subtask 5.4.

Task 8 – Design and Economics of Site Specific Control System

After completion of testing and analysis of the data, the requirements and costs for full-scale, permanent commercial implementation of the necessary equipment for mercury control using sorbent injection technology will be determined. It will be necessary to meet with PG&E engineering and environmental affairs personnel to develop plant specific design criteria. Process equipment shall be sized and designed based on test results and the plant specific requirements (reagent storage capacity, plant arrangement, retrofit issues, winterization, controls interface, etc.). A conceptual design document shall be developed with drawings and equipment lists. Modifications to existing plant equipment shall be determined and a work scope document developed based on input from the plant that may include modifications to the particulate collector, ash handling system, compressed air supply, electric power capacity, other plant auxiliary equipment, utilities and other balance of plant engineering requirements. Reagent type and sources shall be evaluated to determine the most cost -effective reagent(s) for the site. Operational parameters such as utilizing SO_3 injection may also be included.

A cost estimate to implement the control technology will be developed. This shall include capital cost estimates for mercury control process equipment as well as projected annual operating costs, and impacts such as ash sales. Where possible, order-of-magnitude estimates will be included for plant modifications and balance of plant items

Task 9 – Site Report

A site report documenting all measurements, test procedures, analyses, and results obtained in Tasks 2 through 8 will be prepared. This report shall be a stand alone document providing a comprehensive review of the testing and data analysis.

KEY PERSONNEL

The overall program manager for ADA-ES is Dr. Michael Durham. Jean Bustard is coordinating the efforts among all sites. She is also acting as project manager for the field evaluation at Pleasant Prairie with the assistance of Sheila Haythornthwaite of Orion Power Holdings. Figure 3 presents an overall program organizational chart. Table 11 presents key personnel, their roles and phone numbers for the Brayton Point field evaluation.

Table 11
Key Project Personnel for Brayton Point Hg Field Evalation

NAME	COMPANY	ROLE	PHONE #	EMAIL
Brian Wright	PG&E NEG	Project Manager	508-646-5308	Brian.wright@neg.pge.com
Kenneth Small	PG&E NEG	Plant Environmental Manager	508-646-5220	Kenneth.small@neg.pge.com
Tom Moss	PG&E NEG	Engineering Manager	508-646-5267	Thomas.moss@neg.pge.com
Travis Starns	ADA-ES	Site Project Manager	303-734-1727	traviss@adaes.com
Rui Afonso	Energy & Environmental Strategies	Consultant	508-756-5522	rui.afonso@ees-consultants.com
Michael Durham	ADA-ES	Program Manager	303 734-1727	Miked@adaes.com
Jean Bustard	ADA-ES	Project Manager	303 734-1727	Jeanb@adaes.com
Sharon Sjostrom	Apogee Scientific	Hg S-CEM	303 783-9599	Ssjostrom@apogee-sci.com
Steve Johnson	Quinapoxet Solutions	Consultant	603-425-6765	Stevej.quinny@verizon.net
Cam Martin	ADA-ES	Equipment Design	303 734-1727	Camm@adaes.com
Richard Schlager	ADA-ES	Contracts	303 734-1727	Richards@adaes.com
Connie Senior	Reaction Engineering	Waste Issues	801 364 6925 ext 37	senior@reaction-eng.com
Ramsay Chang	EPRI	Air Toxics Expert	650 855-2535	Rchang@epri.com

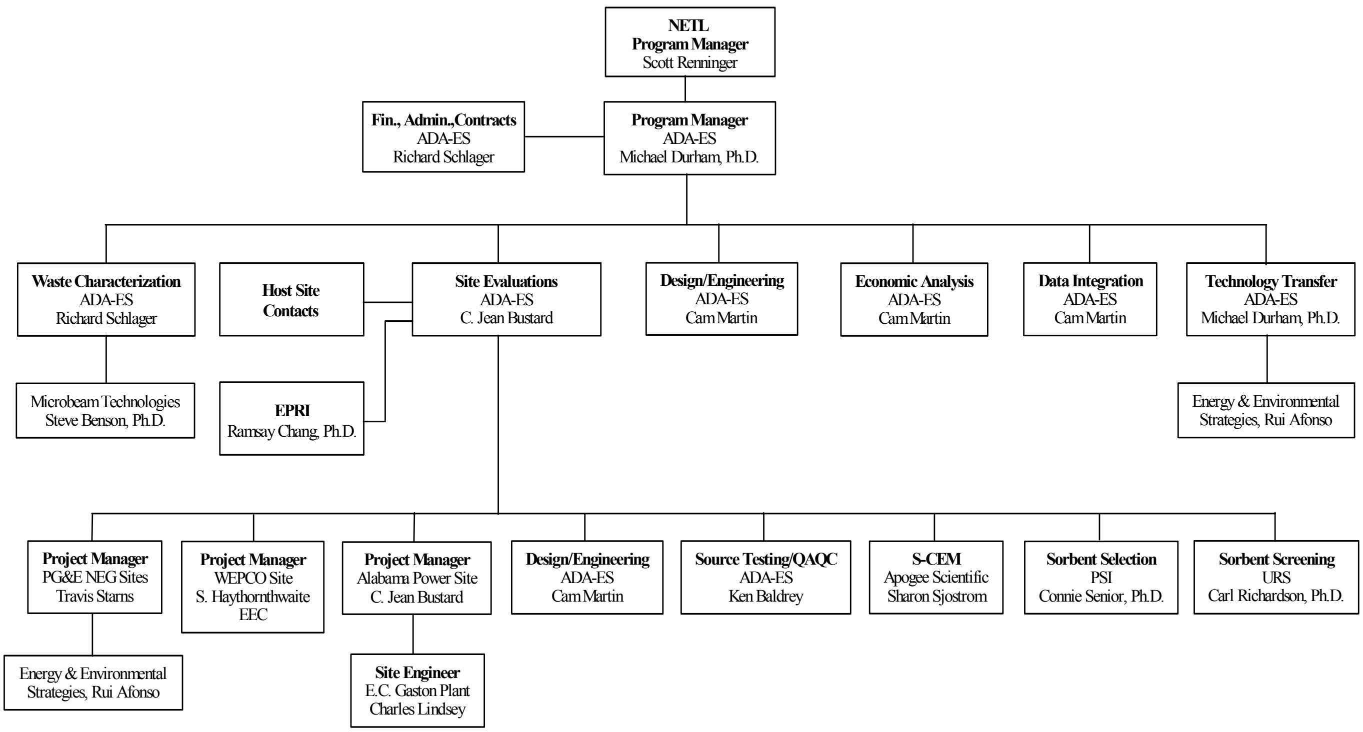


Figure 3
Overall Project Organizational Chart

REFERENCES

1. Meserole, F.B., C.F. Richardson, S.D. Miller, K. Searcy, and R. Chang, "Estimating the Costs of Electric Utility Mercury Control Using Sorbent Injection," Air & Waste Mange. Assoc., Conference Proceedings, 93rd Annual Meeting, June 2000.

APPENDIX A
DESCRIPTION OF FIXED-BED MERCURY ABSORPTION SCREENING DEVICE

BENCH SCALE FIXED BED ADSORPTION TEST DEVICE

Mercury adsorption tests are conducted by saturating sorbents with either elemental mercury or mercuric chloride in the presence of simulated flue gas. The test apparatus is illustrated in Figure A-1. In the laboratory, simulated flue gas is prepared by mixing heated nitrogen gas streams containing SO_2, HCl, NO_x, CO_2, H_2O, and O_2. Mercury is injected into the gas by contacting nitrogen carrier gas with either recrystallized mercuric chloride solids or with an elemental mercury permeation tube (VICI Metronics) housed in a mercury diffusion vessel. Mercury concentration is controlled by the temperature of the diffusion vessel and the nitrogen carrier gas flow rate. During field testing, actual flue gas is drawn into the apparatus.

Sorbents are mixed in a sand diluent prior to being packed in a temperature-controlled, adsorption column (1.27 cm ID). A ratio of 20 mg sorbent to 10 g of sand is generally used for carbon-based sorbents and zeolites, and 200 mg sorbent to 10 g of sand was used for fly ashes. These mass-loadings are chosen to achieve reasonable mercury breakthrough times with the respective sorbents. Prior to flue gas exposure, the sorbent fixed-bed is heated to the desired temperature for periods up to one hour. During this time, the flue gas is by-passed directly to the analytical system to determine the “inlet” mercury concentration. Adsorption tests were initiated by flowing flue gas downward through the fixed-bed column at a flow rate near 1 L/min. Mercury measurements are made with a mercury semi-continuous emissions analyzer (S-CEM) described later in this section.

The amount of mercury exiting the sorbent column is measured on a semi-continuous basis. Gas is passed through the column until 100% of the inlet mercury is detected at the outlet (100% breakthrough). The 100% breakthrough (equilibrium) capacity of the sorbent (µg Hg/g sorbent) is determined by summing the total mercury adsorbed until the time when the outlet mercury concentration is first equal to the inlet concentration.

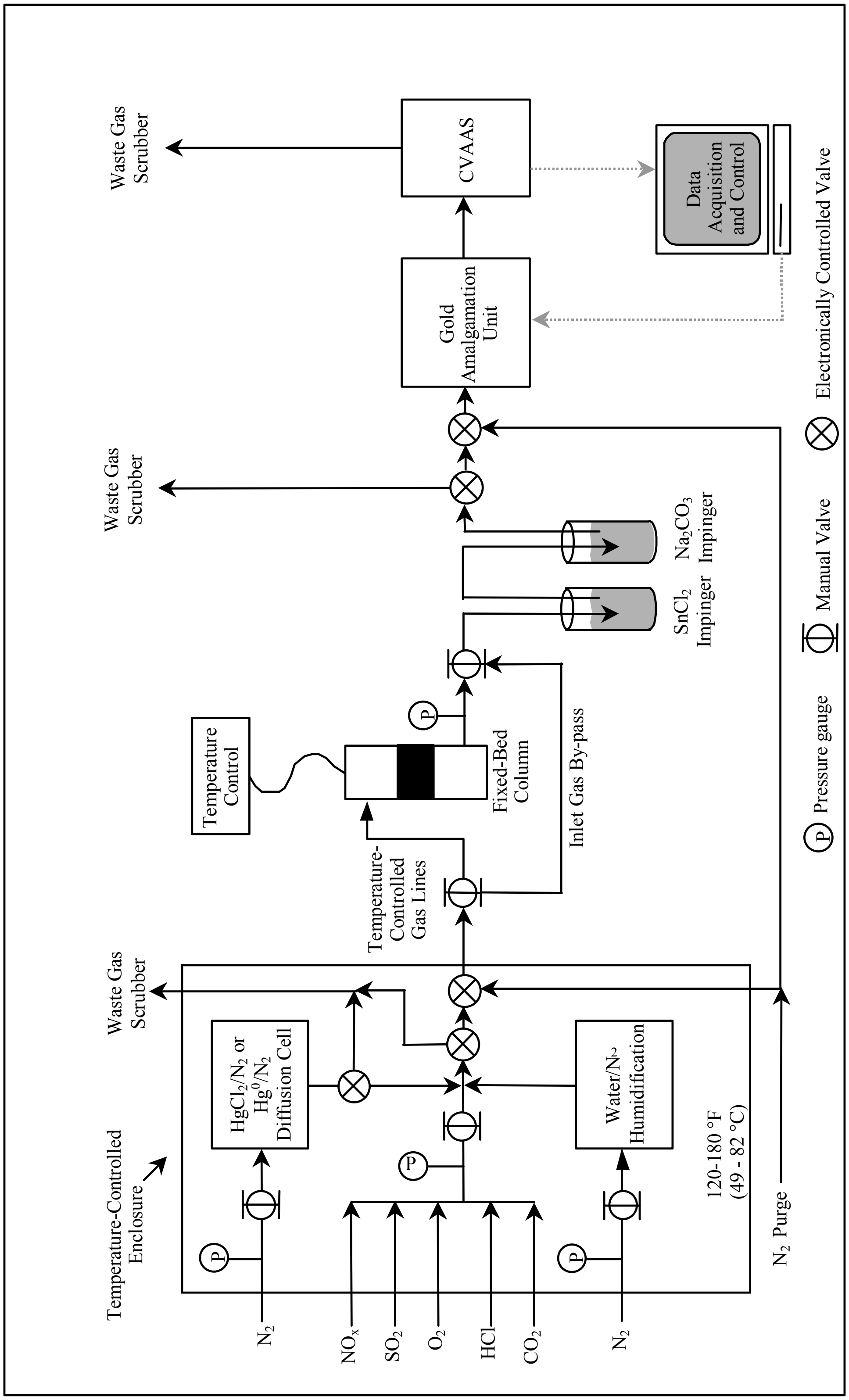


Figure A-1

Bench Scale Fixed Bed Adsorption Test Device

APPENDIX B
SORBENT SELECTION CRITERIA

DRAFT
REQUEST FOR ALTERNATIVE SORBENTS

The program called "Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Mercury Control Systems on Non-Scrubbed Coal-Fired Boilers" is sponsored by DOE, EPRI, and EPA. The program is being conducted by ADA Environmental Solutions (ADA-ES) and its team members. The overall objective is to determine the cost and impacts of sorbent injection into particulate control devices for various mercury removal levels at full-scale, coal-fired power plants.

Full-scale sorbent injection will be tested at four sites as shown below.

Test Site	Coal	Particulate Control
PG&E NEG Salem Harbor	Low S. Bituminous	Cold Side ESP
PG&E NEG Brayton Point	Low S. Bituminous	Cold Side ESP
WEPCO Pleasant Prairie	PRB	Cold Side ESP
Alabama Power Gaston	Low S. Bituminous COHPAC FF	Hot Side ESP

At each site, two sorbents will be evaluated for one week and, if promising, another two weeks of testing may be conducted. A standard activated carbon will be included at each of the test sites. It is expected that the standard sorbent will be a lignite-derived activated carbon, supplied by American Norit™. Norit has quoted delivered prices for FGD activated carbon for these demonstrations of $0.44/pound and has guaranteed availability of the product. The second sorbent will be site-specific, either carbon or ash-based products that show the appropriate capacity for mercury uptake, are economically attractive and readily available in appropriate quantities.

ADA-ES, as prime contractor on the project, is looking for sorbents other than the baseline FGD carbon that can be tested at full scale. ADA-ES envisions a multi-step process for evaluating alternative sorbents, leading to full scale testing as follows.

1. <u>Request for Evaluation</u>. The vendor or developer of an alternative sorbent submits a request for evaluation to ADA-ES. This request should contain enough information to allow ADA-ES and the members of the team to make a decision as to whether the sorbent is a candidate for testing. At a minimum, this request should

a) describe the sorbent in non-proprietary terms (note that the name of the sorbent and developer can be kept confidential in public release of information, but will be disclosed to team members, as well as to DOE, EPA, and EPRI),

b) provide evidence that the cost for removing mercury (per pound of mercury removed) will be at least 25% less than that of FGD carbon (including not only the cost for producing the carbon but transportation, handling, feeding, and waste handling costs that may differ from FGD),

c) demonstrate that the sorbent will be available in quantities of a minimum of 15,000 lbs for a one week test; note that the amount required is site-specific and some sites may require as much as 250,000 lbs minimum, and

d) provide evidence that sufficient quantities will be available to supply at least 100 tons per year by 2007, when mercury emission regulations for coal-fired power plants will be in force.

2. Laboratory characterization. If the team members feel that the sorbent has potential based on the information disclosed in Step 1, then a small sample of sorbent will be provided by the sorbent developer for characterization by URS Corporation (previously Radian) as to the capacity and reactivity of the sorbent. Cost for these tests will be paid for by the vendor or developer.

3. Estimate of sorbent requirements. The team members will use information from Step 2 to calculate how much sorbent will be required per pound of mercury removed and will compare this against the baseline sorbent. If the amount is reasonable from both an operational and cost standpoint, the sorbent will be selected for small-scale field screening.

4. Small-scale field screening. The sorbent will be tested at the specific site using a small fixed bed screening device supplied by URS Corporation.

5. Final evaluation decision. The team will evaluate all the results (cost and performance) and decide whether or not to go ahead with the full scale testing. The plant personnel at the site will review the sorbent data and have the right to refuse to test the sorbent if there is the potential for negative operational impacts such as a) corrosion due to operation at low temperature; b) deposition on duct internals; c) impacts on ash; d) ESP/FF operating characteristics.

6. Field testing. If the sorbent is approved at a particular site, the team will conduct one week of full scale testing for the alternative sorbent and for the baseline sorbent. There is the potential for another two weeks of testing at the same site for sorbents that perform well.

Note that information generated or disclosed in the process described above will be made available to ADA-ES and all team members as well as to the sponsoring agencies (DOE, EPA, EPRI).

APPENDIX C
DESCRIPTION OF SEMI-CONTINUOUS EMISSIONS MONITOR FOR MERCURY

Mercury S-CEM

A semi-continuous mercury analyzer will be used during this program to provide near real-time feedback during baseline, parametric and long-term testing. Continuous measurement of mercury at the inlet and outlet of the particulate collector is considered a critical component of a field mercury control program where mercury levels fluctuate with boiler operation (temperature, load, etc.) and decisions must be made concerning parameters such as sorbent feed rate and cooling. The analyzers that will be used for this program consist of a commercially available cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). Radian developed this type of system for EPRI (Carey, et al., 1998). A sketch of the system is shown in the figure below. One analyzer will be placed at the inlet of the particulate collector and one at the outlet of the particulate collector during this test program.

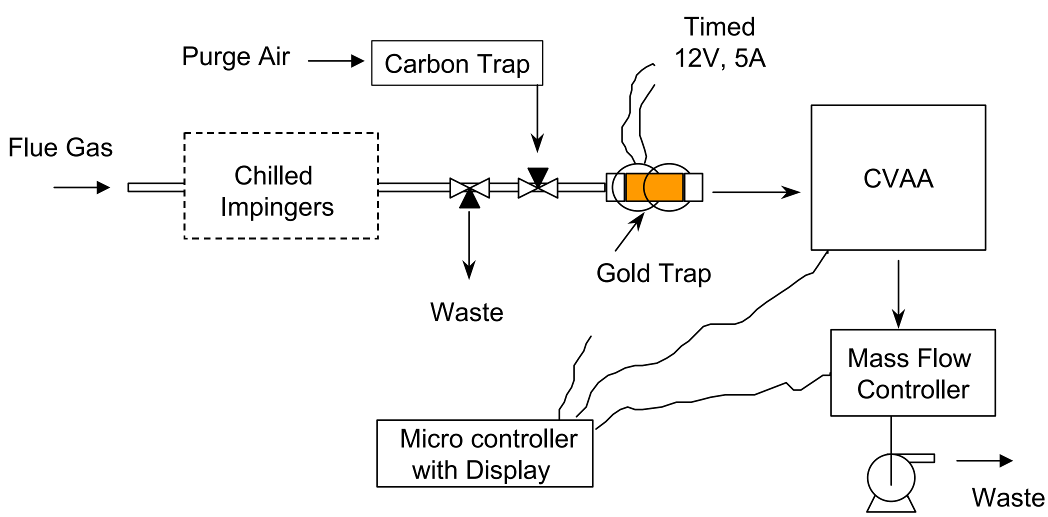


Figure C-1

Sketch of Mercury Measurement System

Although it is very difficult to transport non-elemental mercury in sampling lines, elemental mercury can be transported without significant problems. Since the Au-CVAAS measures mercury by using the distinct lines of UV absorption characteristic of elemental Hg (Hg^0), the non-elemental fraction is either converted to elemental mercury (for total mercury measurement) or removed (for measurement of the elemental fraction) near the sample extraction point. This minimizes any losses due to the sampling system.

For total vapor-phase mercury measurements, all non-elemental vapor-phase mercury in the flue gas must be converted to elemental mercury. A reduction solution of stannous chloride in hydrochloric acid is used to convert Hg^{2+} to Hg^0. The solution is mixed as prescribed in the draft Ontario Hydro Method for manual mercury measurements.

To measure speciated mercury, an impinger of potassium chloride (KCl) solution mixed as prescribed by the draft Ontario Hydro Method is placed upstream of the stannous chloride solution to capture oxidized mercury. Unique to this instrument is the ability to continuously refresh the impinger solutions to assure continuous exposure of the gas to active chemicals.

The Au-CVAAS system is calibrated using elemental mercury vapor. The instrument is calibrated by injecting a metered volume of mercury-laden air into the analyzer. The mercury-laden air is from the air-space of a vial containing liquid mercury at a precisely measured temperature. The concentration of the mercury in the air is determined by the vapor pressure of the mercury at that temperature.

The Au-CVAAS can measure mercury over a wide range of concentrations. Since the detection limit of the analyzer is a function of the quantity of mercury on the gold wire and not concentration in the gas, the sampling time can be adjusted for different situations. Laboratory tests with stable permeation tube mercury sources and standard mercury solutions indicate that the noise level for this analyzer is 0.2 ng mercury. It is reasonable to sample at 50 – 100 times the noise level, therefore, during field testing the sampling time is set so at least 10 ng mercury is collected on the wire before desorption. The following table shows the sampling time required for different concentrations of mercury in the flue gas with 2 liters per minute sample flow.

Sampling Time Required for Au-CVAA Analyzer

VAPOR-PHASE MERCURY CONCENTRATION (μG/M^3)	MINIMUM SAMPLE TIME (MIN)	NOISE LEVEL (μG/M^3)
5	1	0.1
2.5	2	0.05
1	5	0.02
0.5	10	0.01

An oxygen analyzer will be placed downstream of the Au-CVAAS to monitor and store the oxygen levels in the gas stream. This is particularly useful when measuring changes in mercury across a pollution control device on a full-scale unit where air inleakage into the unit may dilute the gas sample and bias results. It is also useful to assure that no leaks develop in the sampling system over time.

Particulate is separated from the gas sample using a self-cleaning filter arrangement modified for use with this mercury analyzer under an EPRI mercury control program. This arrangement uses an annular filter arrangement where excess sample flow continuously scours particulate from the filter so as to minimize any mercury removal or conversion due to the presence of particulate.

The mercury analyzer described has been used extensively for lab testing and field testing at three full-scale coal-fired power plants burning Powder River Basin (PRB), eastern bituminous, and lignite coals under EPRI programs. Although draft Ontario Hydro mercury measurements were not conducted while the analyzer was on-site, levels measured by the analyzer were well within the range expected based on previous measurements with either the draft Ontario Hydro Method or a solid carbon trap.

In order to assure the quality of the data to be obtained during the field operations, Standard Operating Procedures have been developed and will be followed for these tests.

APPENDIX D
REQUEST FOR PROPOSAL FOR ONTARIO HYDRO TESTING

REQUEST FOR PROPOSAL
MERCURY SAMPLING AT BRAYTON POINT

Background

To address critical questions related to cost and efficiency of mercury control technologies, the U.S. Department of Energy (DOE) has undertaken an initiative titled "Testing and Evaluation of Promising Mercury Control Technologies for Coal-Based Power Systems" for the purpose of collecting cost and performance data with parametric and long term field experiments at power plants with existing air pollution control devices. Results of this project will be utilized by the U.S. EPA, the DOE, and others to develop mercury control regulations for coal-fired power plants.

ADA Environmental Solutions (ADA-ES), under contract with the U.S. Department of Energy, National Energy Technology Laboratory (NETL), is conducting full-scale high-efficiency mercury removal tests at selected electric utilities. As part of this effort, dry sorbent injection upstream of an electrostatic precipitator will be evaluated at PG&E NEG Brayton Point Station. ADA-ES will team with PG&E NEG, the Electric Power Research Institute (EPRI), Hamon Research Cottrell, and others on this project. A critical part of this work will be characterization and measurement of particle-bound and vapor phase mercury upstream and downstream of the ESP's at Brayton Point on Unit 1.

ADA-ES is seeking a qualified Contractor to conduct the necessary mercury speciation and related stack sampling for this program. The work requested is similar in scope to EPA's 1999 Information Collection Request (ICR) for mercury emissions from coal-fired power plants.

Proposals are solicited based on the following Scope of Work, Performance Requirements, and Additional Requirements. Proposal content and format are at the discretion of the bidder.

SCOPE OF WORK

Characterization and speciation of mercury will be conducted in two separate campaigns. The first (Baseline) source test will be conducted prior to the start of mercury sorbent injection. The Baseline test will then be followed by a 3 – 4 week parametric evaluation of activated carbon and other sorbents for mercury control at various process conditions. At the conclusion of the parametric evaluation, a to-be-determined, Optimized Condition, will be evaluated. A second set of mercury measurements, identical in scope to the baseline, will then be conducted at the optimized condition.

Baseline Condition

Services and testing requested for the Baseline Condition are as follows:
Source measurements of elemental, oxidized, and particle-bound mercury per the Ontario-Hydro Method[1] at the PG&E NEG Brayton Point Station in Somerset, MA. Triplicate runs are to be conducted at two locations:

East inlet to first ESP
East outlet to the second ESP

Optimized Condition

Services and testing requested for the Optimized Condition are as follows:

1. Source measurements of elemental, oxidized, and particle-bound mercury per the Ontario-Hydro Method[1] at the PG&E NEG Brayton Point Station in Somerset, MA. Triplicate runs are to be conducted at the same locations as for the Baseline tests. Inlet and outlet sampling runs shall be conducted concurrently.

Quality Assurance/Quality Control Plan

Contractor shall prepare and submit a pre-test Quality Assurance/Quality Control (QA/QC) Plan for the activities included in the Scope of Work. This plan will be reviewed and approved by ADA-ES and research partners prior to the start of the test program.

Laboratory Analysis

Laboratory analytical procedures and the labs proposed for the project are to be identified in the proposal. Laboratory QA/QC procedures, including blank analysis and spiking of samples, shall be detailed in the QA/QC Plan.

Contingency

Repeat of sampling runs due to non-representative process conditions may be required, at the discretion of the Test Coordinator. Pricing for additional sampling on a Time-and-Materials basis is requested.

Contractor Responsibility

- Contractor shall provide all equipment and personnel to accomplish the Scope of Work.
- Contractor shall provide any on-site temporary lab facilities necessary to complete the scope of work, independent of plant facilities.
- Contractor shall be responsible for overseeing and coordinating all analytical laboratory work.

Plant Responsibility

- Space for a temporary laboratory trailer will be provided in close proximity to the test locations. Electrical power for the trailer, as required, will be provided.
- 110 VAC electrical power will be available at each test location. Contractor shall verify the reliability, adequacy, and the location of circuit disconnect(s) prior to test startup.
- Test ports will be cleaned, flanges and caps loosened, prior to test startup.

ADA-ES Responsibility

- ADA-ES will provide a Test Coordinator for the duration of the on-site sampling period. The Test Coordinator will be available to assist the Contractor as necessary and to coordinate with plant personnel.

- The Test Coordinator, in consultation with other research partners, will be responsible for determining when to commence sampling runs and to oversee the process.

- ADA-ES will be responsible for collection of process data, coal samples and ESP hopper ash samples.

Performance Requirements

- Measurements shall be conducted according to standard EPA Reference Methods 1 – 5 [3] and draft Ontario-Hydro method.

- A separate report shall be issued for each of the two sampling campaigns. Report format shall follow EPA's Emission Measurement Center (EMC) guidelines[2]. Field data sheets and chain of custody forms shall be included in appendices.

- Quality assurance and calibration procedures, including laboratory procedures, shall be as specified in EPA Methods 1 – 5 and draft Ontario-Hydro[1, 3]. All quality assurance activities shall be agreed upon and executed as per the QA/QC Plan.

- Acceptance of isokinetic test results shall be based on standard criteria averaged over the entire test run. Determination shall be made at the conclusion of each test run such that a repeat may be conducted immediately in the event of a non-isokinetic result.

- Sample time for each run shall be at least 2 hours with sample volume of >1.0 dscm per the draft Ontario-Hydro specification[1].

Additional Requirements

Specific terms and conditions will be negotiated upon award of contract. The following items are to be considered in proposal submission.

Insurance

Contractor shall provide certification of insurance for all workers, agents, and subcontractors proposed for this project including Worker's Compensation Insurance, Commercial General Liability Insurance, and Commercial Automobile Liability Insurance.

Safety and Work Practice

Contractor shall ensure that its activities and those of its employees, agents, and subcontractors are in compliance with all applicable OSHA and environmental regulatory requirements and with all applicable plant health and safety procedures.

Data Rights and Data Access

Due to the nature of the contractual arrangements for this government project, all data including deliverable reports, original data sheets, and computer generated spreadsheets, with the exception of restricted computer software, are to be available for inspection by the DOE, EPA, and others as authorized by ADA-ES.

Test Observers

Representatives of the EPA and DOE and others as authorized by ADA-ES may be on site during the test period(s) as observers. Details of the work scope and QA/QC procedures as agreed to in the QA/QC plan will not be affected.

Cost Breakdown

Proposal bid pricing is requested as fixed price for the entire Scope of Work excluding the Baseline Condition particulate tests that are requested as a separate line item. Pricing for additional work beyond the Scope of Work on a Time-and-Materials basis is also requested.

References and Work Experience

Relevant experience of bidder with the specific test methods, including that of laboratory participants, is requested.

Schedule

Proposals are to be submitted to ADA-ES on or before March 1, 2002. Contract award is expected by March 15, 2002. A Draft QA/QC Plan is to be submitted within 30 days of award of contract. Baseline testing is scheduled for June 3-7, 2001. Testing of the Optimized Condition is scheduled for early August. Please indicate availability and notification requirements for any schedule changes in proposal.

Additional Information

Site visits, if necessary, may be scheduled by contacting ADA-ES, who will arrange such with Alabama Power Company. Questions and requests for additional information, as required to respond to this Request For Proposal, should be addressed to:

ADA-ES
8100 SouthPark Way
Unit B2
Littleton, Colorado 80120

Attn. Ken Baldrey
Technical Services Manager
303-734-1727
303-734-0330
kenb@adaes.com

REFERENCES

1. "Standard Test Method for Elemental, Oxidized, Particle-Bound, and Total Mercury in Flue Gas Generated from Coal-fired Stationary Sources (Ontario Hydro Method), ASTM draft method, available from U.S. EPA OAQPS Emission Measurement Center.

2. "Preparation and Review of Emission Test Reports", U. S. EPA OAQPS Emission Measurement Center Guideline Document GD-043, Nov. 1998.

3. EPA Methods 1 through 5, Code of Federal Regulations, Title 40, Part 60, Appendix A, July 1991. Available from the U.S. Environmental Protection Agency's OAQPS Emission Measurement Center.

Figure D-1
Process Layout

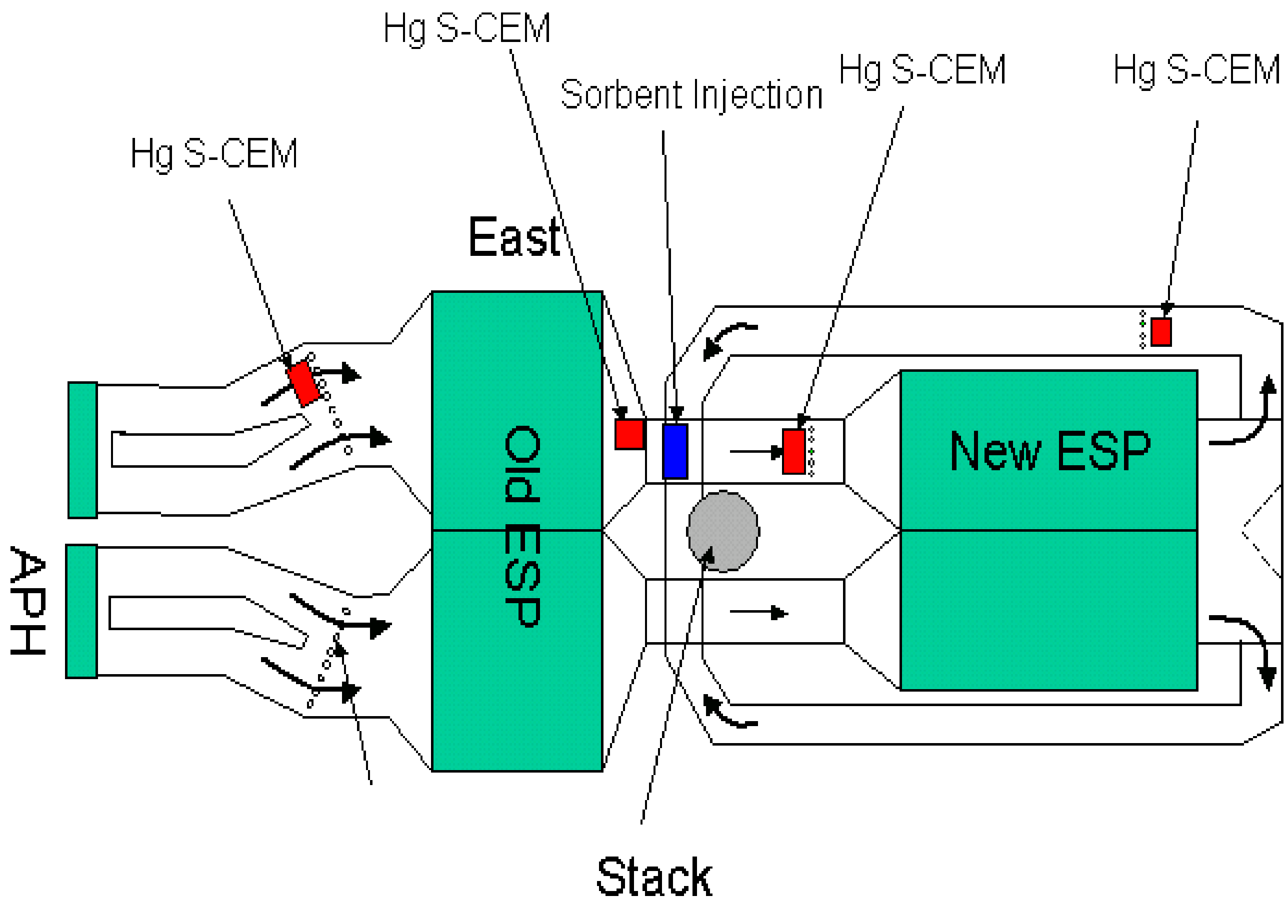
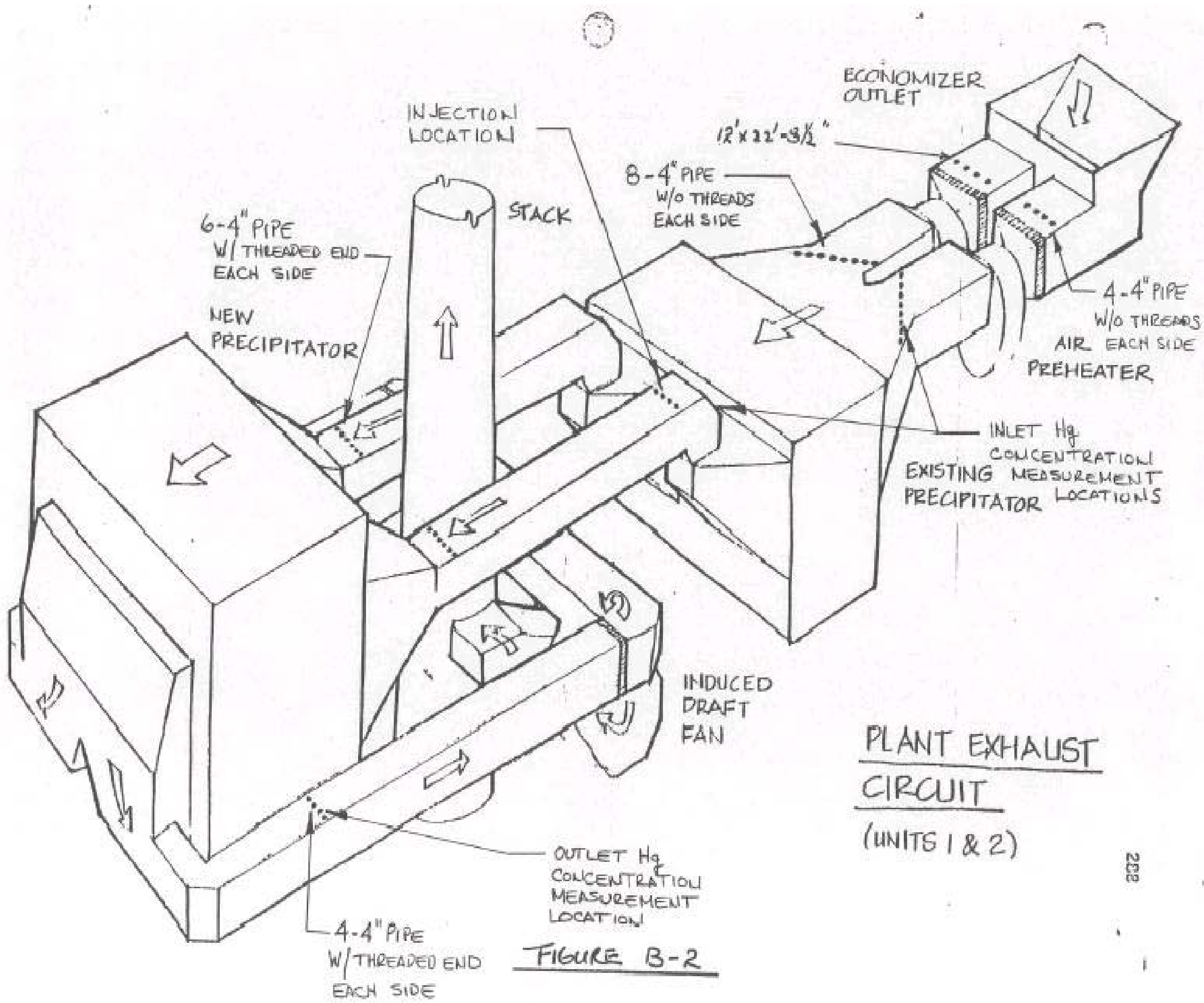


Figure D-2
Precipitator Layout Brayton Point, Unit 1



APPENDIX B

BASELINE TESTS

ADA Environmental Solutions, LLC

8100 SouthPark Way, B-2
Littleton, Colorado 80120
Fax: 303.734.0330
303.734.1727 or 1.888.822.8617

memorandum

To: Brian Wright, Ramsay Chang, Rui Afonso, Jean Bustard, Steve Johnson, Sharon Sjostrom, Paul Harrington, Mike Martin

From: Travis Starns

CC: Mike Durham, Cam Martin, Ken Baldrey, Richard Schlager, Scott Renninger, Jim Kilgroe, Jeff Ryan, Rob LaCount, Thomas Moss, Herb Stowe, Mike Kane, Blair Seckington, Connie Senior, Larry Monroe

Date: June 10, 2002

RE: Preliminary Baseline Results

This memo provides a status update for the NETL mercury control evaluation being conducted on Brayton Point Unit 1. The current test schedule can be found on page 5 of this document.

Last week, the baseline testing series was completed. During this testing series, baseline Ontario Hydro tests were performed on Unit 1. These tests were performed by TRC Environmental Corporation under the direction of Mike Martin and were conducted across both ESP's. On June 6, two Ontario Hydro runs were performed and the final run was completed the following day. Through out the duration of these tests, Unit 1 was held at full load approximately 245 MW.

During the Ontario Hydro tests, the Hg S-CEMs were also in operation. The Hg S-CEMs supplied by Apogee Scientific measured the vapor phase mercury concentrations in the flue gas inlet and outlet of both ESPs. The table below shows the approximate vapor phase mercury levels present in the flue gas during the Ontario Hydro tests. Data from the S-CEMS are still being analyzed, but showed that the mercury levels decreased significantly just before the start of the Ontario Hydro tests. Mercury concentrations increased over the weekend to levels more typical of those measured during the prebaseline measurements in June 2001 (inlet values between 2 and 4 $\mu g/Nm^3$).

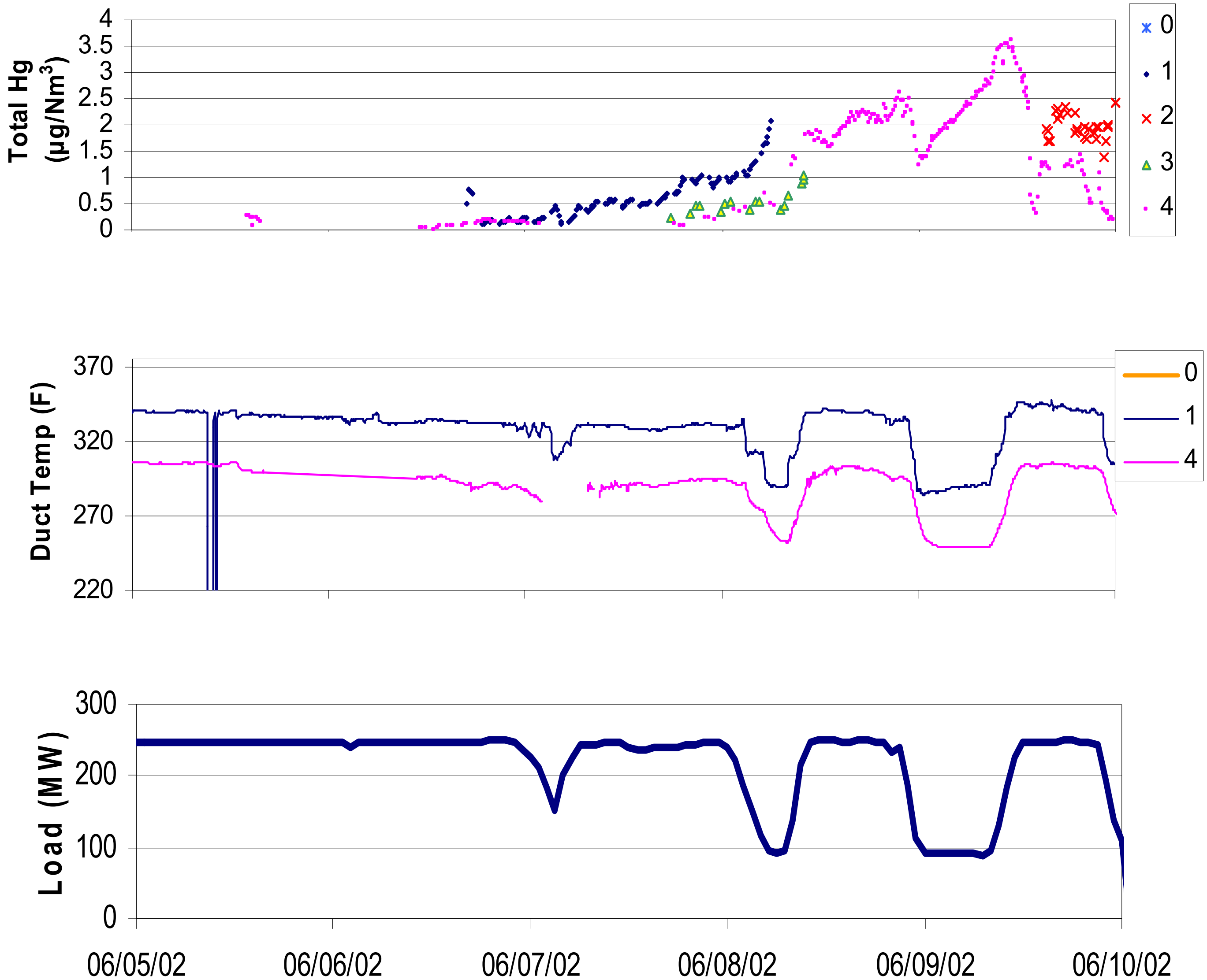
Inlet to old ESP Total vapor phase Hg concentration $\mu g/Nm^3$	Outlet to new ESP Total vapor phase Hg concentration $\mu g/Nm^3$
~ 0.4 – 0.5	~ 0.1 – 0.2

This week is the beginning of the parametric testing series. However, due to a boiler tube leak Unit 1 has come off-line thus testing has ceased. Testing will resume as soon as Unit 1 returns to normal operation. The future test schedule and parameters can be found in the test plan, which is on page 2 of this document.

Planned Full-Scale Test Sequence for Brayton Point

Test Description	Dates	Parameters/Comments	Boiler Load
Baseline tests (No injection)	June 5 - 8	Day 1 – Ontario Hydro Tests Day 2 – Ontario Hydro Tests Day 3 – Ontario Hydro Tests Day 4 – Increase residence time in duct Operate at low load[1], no carbon injection (*Perform test condition on Saturday, June 8, 2002*)	Full Load – 24 hours a day during Ontario Hydro Tests [1] Low Load – 06:00-20:00
Parametric Week 1 (Baseline Hg Capture WRT Operational Changes and Carbon Injection – FGD)	June 10-14	Day 1 – ***No testing, Unit 1 Tube leak will resume testing ASAP.*** Day 2 – ***No testing, Unit 1 Tube leak will resume testing ASAP*** Day 3 – multiple nozzle lance injection (Operate at Full Load) * Day 4 – Inject at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Inject at 3 lbs/Mmacf (0.08 lbs/Mmbtu) (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week2 (Carbon Injection – FGD, SAI, CC)	June 17-21	Day 1 – Inject at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 2- Load Silo w/ SAI, inject at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Inject SAI at 10 lbs/Mmacf (0.25 lbs/Mmbtu), feed out sorbent (Operate at Full Load) * Day 4 – Load silo w/ CC, Inject CC at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Inject CC 10 lbs/Mmacf (0.25 lbs/Mmbtu), Feed out sorbent (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week 3 (Carbon Injection – Donau, FGL, EPRI)	June 24-28	Day 1 – Load Silo w/ Donau, Inject AS#3 at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 2 – Inject Donau at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Load Silo w/ FGL, Inject FGL at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 4 – Inject FGL at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Load Silo w/ EPRI, Inject EPRI at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week 4 (Carbon Injection –EPRI, FGD)	July 1-5	Day 1 – Inject EPRI at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 2 – Load silo/ with Norit FGD, Detune ESP[3] (Reduce power section by section), injection concentration TBD (Operate at Full Load) * Day 3 – SO_3 Conditioning on, Injection concentration TBD (Operate at Full Load) * Day 4 – Contingency Day 5 – Contingency	* Full Load – 06:00-20:00
Parametric Week 5	July 8-12	Day 1 - 5 – Contingency	
Long Term Test (Carbon Injection – Norit FGD)	July 15 – 25	Sorbent – Norit FGD, injection concentration TBD July 22 – OH (Operate at Full Load) * July 23 – OH (Operate at Full Load) * July 24 – OH (Operate at Full Load) *	* Full Load – July 22-24 (24 Hours a day)

Figure 1. Trend Data – Baseline Testing Series



APPENDIX C

PARAMETRIC TESTS

PARAMETRIC TEST MEMOS AND TREND DATA

Week 1 Trend Data – June 13, 2002

Week 2 Trend Data – June 17, 2002

Week 3 Trend Data – June 24, 2002

Week 4 Trend Data – July 1, 2002

Week 5 Trend Data – July 11, 2002

ADA Environmental Solutions, LLC

8100 SouthPark Way, B-2

Littleton, Colorado 80120
Fax: 303.734.0330
303.734.1727 or 1.888.822.8617

memorandum

To: Brian Wright, Ramsay Chang, Rui Afonso, Jean Bustard, Steve Johnson, Sharon Sjostrom, Paul Harrington, Mike Martin

From: Travis Starns

CC: Mike Durham, Cam Martin, Ken Baldrey, Richard Schlager, Scott Renninger, Jim Kilgroe, Jeff Ryan, Rob LaCount, Thomas Moss, Herb Stowe, Mike Kane, Blair Seckington, Connie Senior, Larry Monroe, Doug Bondar, Allen Sload, Ken Small

Date: June 10, 2002

RE: Parametric tests week of June 10

This memo provides a status update for the NETL mercury control evaluation being conducted on Brayton Point Unit 1.

Tests planned for the week of June 10 included evaluation of the effect of detuning the ESP on baseline mercury removal, two different lance designs, and two different injection concentrations of Norit FGD. Unit 1 tripped off line Sunday night for a boiler tube leak. The unit was off line until Wednesday afternoon. Unit 1 operated at full load on Thursday, but that night a problem with a steam valve forced reduced load operation. Until repairs are made, maximum load is 92% of full load. This is still an acceptable test condition.

Measuring mercury with the S-CEMs has been more challenging than anticipated. This was not expected as no unusual troubles occurred during pre-baseline testing in June 2001. Apogee is working through the problems. In addition, the analyzers have tripped off line several times due to ground fault trips during heavy rains. Additional waterproofing has been installed around all of the electrical connections. *Note: when the analyzers trip due to a power loss chemical is drawn into the system and before restart all transport surfaces must be cleaned. This is down time of about ½ day.*

The analyzers are set up for sampling at 4 locations:

1. Inlet, upstream of the old ESP;
2. Mid-Point 1, outlet of the old ESP upstream of carbon injection;
3. Mid-Point 2, inlet of the new ESP, downstream of carbon injection;
4. Outlet, downstream of new ESP.

One analyzer at the Inlet measures locations 1 and 2 and one analyzer at the outlet measures locations 3 and 4. The primary problems have occurred with the inlet analyzer. Preliminary diagnostics indicate an aerosol (possible SO_3) is fouling the internal surfaces. The outlet analyzer appears to be functional.

Although carbon was injected for short periods on Thursday and Friday, a good test run was not completed. At this time we are a full week behind schedule.

Our plan for the week of June 17 is to begin parametric tests with the FGD carbon using only the outlet analyzer and measurements from location 3 and 4. Ideally we would like to have measurements from locations 2 and 4. Additional hot line has been ordered to try and connect this sampling location 2 to the outlet analyzer.

An updated schedule will be developed after we see how testing progresses this week.

ADA Environmental Solutions, LLC

8100 SouthPark Way, B-2
Littleton, Colorado 80120
Fax: 303.734.0330
303.734.1727 or 1.888.822.8617

memorandum

To: Brian Wright, Ken Small, Rui Afonso

From: Jean Bustard, Sharon Sjostrom

CC: Mike Durham, Travis Starns

Date: June 20, 2002

RE: Week 1 parametric test – actual test conditions

Carbon injection tests for mercury control on Unit 1 began on Monday June 17. Our tests were delayed 1 week due to a unit outage and start-up troubleshooting with the analyzers. The original test plan, see attached, called for parametric testing of FGD carbon at 1, 3 and 10 lbs/Mmacf. These injection concentrations were estimated based on results from the Pleasant Prairie tests.

Mercury measurements and early tests had some unexpected results. They include:

1. The first tests with carbon injection showed removal efficiencies slightly higher than expected at the highest injection rate (10 lbs/Mmacf). The in-flight removal efficiency was much higher than expected. In-flight commonly refers to removal that occurs in the inlet duct before the carbon enters the ESP. The in-flight measurement is made about 20 – 25 ft downstream of injection. Preliminary results at 10 lbs/Mmacf showed about 70% removal across the new ESP and 95% of that in-flight before entering the old ESP.
2. Testing at Pleasant Prairie and Gaston did not indicate that we were getting in-flight removal at these high levels. We thought we saw about 30% in-flight removal at both sites. The EPRI model predicting mercury removal at different injection rates is based on in-flight removal. The model predicted that we should have seen higher removal efficiencies at the higher injection concentrations at Pleasant Prairie. Noting this, we wondered if we would see higher removal efficiencies here at higher rates since most of the removal appears to occur in-flight. With this in mind, we planned for a short test at 20 lbs/Mmacf to project the upper limit.
3. On Wednesday June 19 we planned two short tests: a test in the morning at 1 lb/Mmacf to find the lower threshold, and an afternoon test at 20 lbs/Mmacf to establish the upper limit. The first test was 3 hours and the second test was 2.8 hours.
4. The preliminary results from tests this week were removal efficiencies less than 20% at 1 lb/Mmacf and removal greater than 80% during the 20 lb/Mmacf test. Note – these are vapor-phase mercury removals across the new ESP only.

Table 1 compares preliminary mercury removal efficiencies measured across the new ESP at Brayton Point with results from Pleasant Prairie. It is important to note that the mercury analyzers measure only vapor phase mercury. Particulate phase mercury is not measured and some particulate-phase mercury may be present at the inlet to the old ESP that will presumably be removed in the ESPs. It is also important to remember that the parametric tests are conducted under steady state conditions and that in previous tests mercury removal varied somewhat when carbon was injected 24 h/day injection during the long term tests. Data at the higher injection rates are presented as “greater than” a value until the data have undergone final QA examination. All of the tests in Table 1 were conducted with Norit FGD.

We would like to discuss revising the test plan to repeat the 20 lb/Mmacf test with FGD the week of July 1.

Table 1:

Day	Inj. Conc (lbs/Mmacf)	RE New ESP (%)	PPPP Results (%)
Wednesday June 19 am	1	12	45
Monday June 17	3	48	55
Tuesday June 18	10	>70	60 - 65
Thursday June 20	10	>70	60 - 65
Wednesday June 19 pm	20	>80	60 - 65

Initial Full-Scale Test Sequence for Brayton Point

Test Description	Dates	Parameters/Comments	Boiler Load
Baseline tests (No injection)	June 5 - 8	Day 1 – Ontario Hydro Tests Day 2 – Ontario Hydro Tests Day 3 – Ontario Hydro Tests Day 4 – Increase residence time in duct Operate at low load[1], no carbon injection (*Perform test condition on Saturday, June 8, 2002*)	Full Load – 24 hours a day during Ontario Hydro Tests [1] Low Load – 06:00-20:00
Parametric Week 1 (Baseline Hg Capture WRT Operational Changes and Carbon Injection – FGD)	June 10-14	Day 1 – ***No testing, Unit 1 Tube leak will resume testing ASAP.*** Day 2 – ***No testing, Unit 1 Tube leak will resume testing ASAP*** Day 3 – multiple nozzle lance injection (Operate at Full Load) * Day 4 – Inject at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Inject at 3 lbs/Mmacf (0.08 lbs/Mmbtu) (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week2 (Carbon Injection – FGD, SAI, CC)	June 17-21	Day 1 – Inject at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 2- Load Silo w/ SAI, inject at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Inject SAI at 10 lbs/Mmacf (0.25 lbs/Mmbtu), feed out sorbent (Operate at Full Load) * Day 4 – Load silo w/ CC, Inject CC at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Inject CC 10 lbs/Mmacf (0.25 lbs/Mmbtu), Feed out sorbent (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week 3 (Carbon Injection – Donau, FGL, EPRI)	June 24-28	Day 1 – Load Silo w/ Donau, Inject AS#3 at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 2 – Inject Donau at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Load Silo w/ FGL, Inject FGL at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) * Day 4 – Inject FGL at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Load Silo w/ EPRI, Inject EPRI at 1 lbs/Mmacf (0.024 lbs/Mmbtu) (Operate at Full Load) *	* Full Load – 06:00-20:00
Parametric Week 4 (Carbon Injection –EPRI, FGD)	July 1-5	Day 1 – Inject EPRI at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 2 – Load silo/ with Norit FGD, Detune ESP[3] (Reduce power section by section), injection concentration TBD (Operate at Full Load) * Day 3 – SO_3 Conditioning on, Injection concentration TBD (Operate at Full Load) * Day 4 – Contingency Day 5 – Contingency	* Full Load – 06:00-20:00
Parametric Week 5	July 8-12	Day 1 - 5 – Contingency	
Long Term Test (Carbon Injection – Norit FGD)	July 15 – 25	Sorbent – Norit FGD, injection concentration TBD July 22 – OH (Operate at Full Load) * July 23 – OH (Operate at Full Load) * July 24 – OH (Operate at Full Load) *	* Full Load – July 22-24 (24 Hours a day)

ADA Environmental Solutions, LLC

8100 SouthPark Way, B-2
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memorandum

To:	Brian Wright, Ken Small, Hg Project Team
From:	Travis Starns, Jean Bustard, Sharon Sjostrom
CC:	Mike Durham
Date:	June 27, 2002
RE:	Parametric Test Results June 17 - 24

Parametric testing at Brayton Point began on June 17, one week behind schedule. Delays were caused by a plant outage, problems with equipment power and the GFI circuits (we were getting moisture in our equipment circuits which tripped power to these sites), and understanding sample extraction challenges with high SO_3 concentrations. When the tests were started on June 17 there were still interferences from SO_3 conditioning with the measurements at location 1. Testing was started relying primarily on the measurements from locations 3 and 4. The original extraction locations, identified as locations 1 – 4, are shown in Figure 1.

The original test plan called for parametric testing of FGD carbon at 1, 3 and 10 lbs/MMacf. These Injection concentrations were estimated based on results from the Pleasant Prairie tests. Early results indicated that higher injection concentrations should be tested. The first test at 20 lbs/MMacf showed very high removal across the new ESP (>80%). Although checks on the analyzers and extraction systems at locations 3 and 4 indicated that they were functioning properly, the results were so surprising that several days of additional troubleshooting was conducted to verify results. Simultaneously to troubleshooting, testing on the alternative sorbent continued in order to understand if the other carbons had similar behavior.

Table 1 presents the test conditions for the first 11 parametric tests. All of these tests were conducted with the EPRICON (SO_3 conditioning)system operating.. This table also shows short-term mercury removal efficiencies across the new ESP. The data are graphically summarized in Figure 2. Observations include:

FGD Carbon

- FGD carbon tested at 1, 3, 10, and 20 lbs/MMacf.
- Removal efficiencies at 1, 3, and 10 were reasonably close to Pleasant Prairie results.
- At 20 lbs/MMacf, unlike Pleasant Prairie, removal efficiency increased to 90%. After much head scratching and data review, a theory on why there is a difference has been formulated. Sharon Sjostrom and Scott McLaren (Apogee) nicely summarize this theory

with supporting data in a memo, which can be found at the end of this memo. (Thank you Scott for taking the lead on putting these thoughts together.)

Other Sorbents

- Figure 2 also presents results from tests with two of the alternative sorbents:
    - Superior Adsorbents Inc. (SAI), a bituminous activated carbon, and
    - CarboChem (CC), a bituminous activated carbon imported from China.
- These sorbents were tested at 3, 10, and 20 lbs/MMacf.
- At 3 lbs/MMacf SAI and CC had poor removal compared to FGD: 2 and 6% versus 48%.
- At 10 lbs/MMacf SAI and CC performance improved with CC showing 55% removal and SAI showing an average 61% removal, compared to 71% removal with FGD.
- At 20 lbs/MMacf, all carbons showed high removal with a range from 86 to 90%.
- Two lance designs were tested with the SAI carbon. There are four ports at the injection location. With both designs, two lances are inserted into each port to distribute carbon to both the upper and lower sections of the 11 ft duct. Lance design 1 has a single large volume beveled opening oriented counter-current to flow 3 ft below the top of the duct and 4 ft above the bottom of the duct. The large volume beveled opening produces a wide-angle conical plume. Lance design 2 has 8 smaller openings drilled at 1 ft increments along the lance with carbon entering the duct from two sides of the lance normal to flow. The combined area of the smaller nozzles is almost equivalent to the single large volume opening of lance 1 The test showed that there was no difference in performance between the two lance designs, 59% versus 62% (we assume a 10% repeatability between tests). Lance design 2 was left in service for the remainder of the parametric tests.

Mercury Measurements

- Mercury measurements are very difficult at the inlet location 1 due to high SO_3 concentrations from the EPRICON system. After several days of diagnostics and testing solutions, Apogee has minimized fouling in the system at most of the locations. Fouling still occurred in the impingers at location 1 (directly downstream of where SO_3 enter the flue gas) and caused a reduction in measured? mercury concentrations soon after new impingers were installed. To alleviate this problem, Brayton Point installed flange adaptors on the ports upstream of the air preheater on Monday June 24. Apogee moved the extraction probe to location 0 on Wednesday June 26.
- Mercury concentration at location 1 was typically about 3 – 3.5 $\mu g/Nm^3$. When the probe was moved to location 0, mercury concentration increased to nominally 4.5 $\mu g/Nm^3$. This change probably indicates that particulate phase mercury is present at location 1. Mercury removal across the system, old and new ESP, will be presented after we have a chance to track mercury levels at location 0 for a couple of days.

The test schedule continues to evolve as we gather more data and overcome operational problems. Because of the unexpected high mercury removals, Brayton Point has requested that repeat FGD tests at 10 and 20 lbs/MMacf with EPRICON off (this is how they expect to run in the future) and again with EPRICON on to confirm data. We will also run a short, repeat test with FGD and SO_3 at 3 lbs/MMacf. A revised test schedule can be found in Table 2.

Table 1: Preliminary Results From Brayton Point Parametric Tests June 2002

Removal Efficiency (RE) Measured Across the New ESP

Date	Duration (h)	Inj. Concen. (lbs/MMacf)	Sorbent	RE New ESP (%)	Lance Design
6/17/02	6	3	FGD	48	Single Nozzle
6/18/02	6	10	FGD	73	Single Nozzle
6/19/02	2.5	1	FGD	13	Single Nozzle
6/19/02	2.8	20	FGD	90	Single Nozzle
6/20/02	3	10	FGD	71	Single Nozzle
6/21/02	6	3	SAI	6	Single Nozzle
6/22/01	8	10	SAI	62	Single Nozzle
6/24/02		10	SAI	59	Multi Nozzle
6/25/02	6	3	CC	2	Multi Nozzle
6/26/02	6	10	CC	55	Multi Nozzle
6/26/02	3.5	20	CC	86	Multi Nozzle

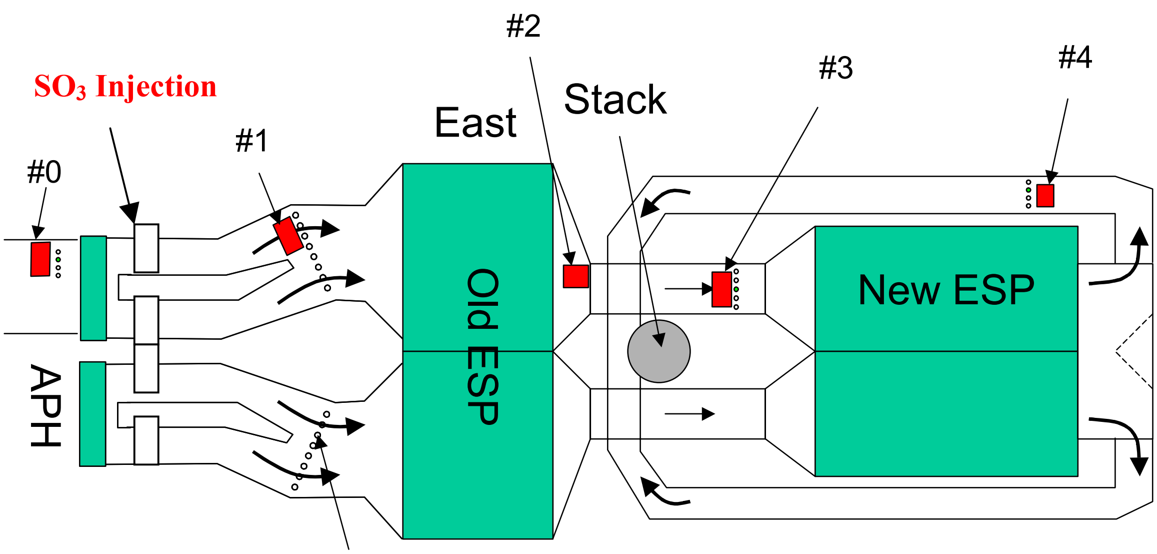

Figure 1. Mercury S-CEM extraction locations.

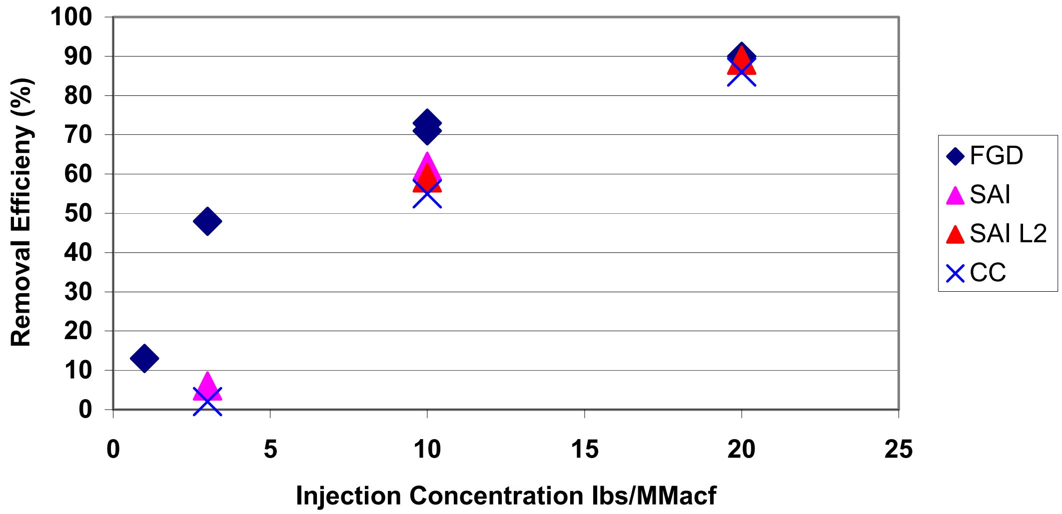

Figure 2. Mercury removal efficiencies measured across new ESP during Brayton Point parametric tests. All test conducted with EPRICON in service.

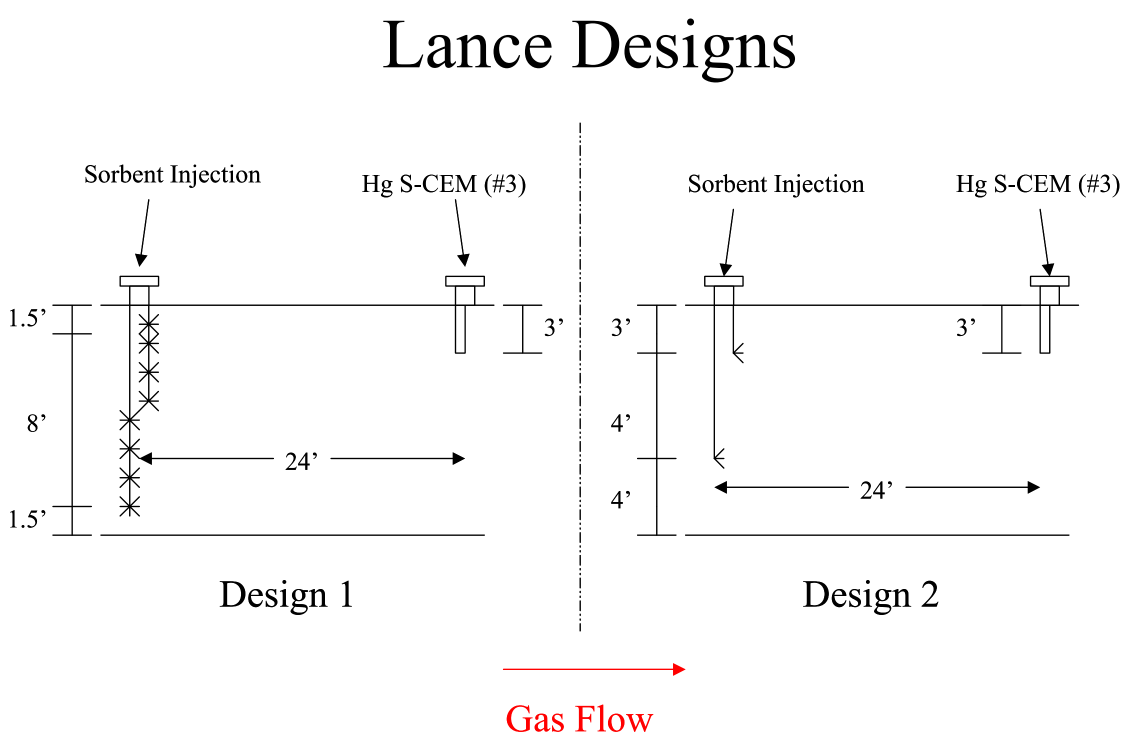

Figure 3. Schematic of two different carbon injection lance designs tested at Brayton Point

Table 2. Planned Full-Scale Test Sequence for Brayton Point

Test Description	Dates	Parameters/Comments	Boiler Load
Baseline tests (No injection)	June 5 - 8	Day 1 – Ontario Hydro Tests Day 2 – Ontario Hydro Tests Day 3 – Ontario Hydro Tests Day 4 – Increase residence time in duct Operate at low load[1], no carbon injection (Perform test condition on Saturday, June 8, 2002)	Full Load – 24 hours a day during Ontario Hydro Tests [1] Low Load – 06:00-20:00
Parametric Week 1 (Baseline Hg Capture WRT Operational Changes and Carbon Injection – FGD)	June 10-14	Day 1 – No testing, Unit 1 Tube leak will resume testing ASAP Day 2 – No testing, Unit 1 Tube leak will resume testing ASAP Day 3 – No testing, Unit 1 Tube leak will resume testing ASAP Day 4 – No testing, Start Up trouble with Hg analyzers Day 5 – No testing, Start Up trouble with Hg analyzers	* Full Load – 06:00-20:00
Parametric Week2 (Carbon Injection – FGD, SAI)	June 17-22	Day 1 – Inject FGD at 3 lbs/Mmacf (0.08 lbs/Mmbtu) (Operate at Full Load) * Day 2- Inject FGD at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Inject FGD at 1 and 20 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Day 4 – Inject FGD at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Feed out sorbent Day 5 – Load Silo w/ SAI, Inject SAI at 3 lbs/Mmacf (0.08 lbs/Mmbtu) * Day 6 - Inject SAI at 10 lbs/Mmacf (0.25 lbs/Mmbtu)*	* Full Load – 06:00-20:00
Parametric Week 3 (Carbon Injection – SAI, CC, Donau, FGD)	June 24-29	Day 1 – multiple nozzle lance injection, Inject SAI. Injection Concentration TBD. Feed out sorbent Day 2 – Load Silo w/ CC, Inject CC at 3 lbs/Mmacf (0.08 lbs/Mmbtu) (Operate at Full Load) * Day 3 – Inject CC at 10 lbs/Mmacf (0.25 lbs/Mmbtu) (Operate at Full Load) * Feed out Sorbent Day 4 – Load Silo w/ Donau, Inject Donau at 3 lbs/Mmacf (0.08 lbs/Mmbtu) (Operate at Full Load) * Day 5 – Inject Donau at 10 lbs/Mmacf (0.25 lbs/Mmbtu) * Feed out Sorbent Day 6 – Load Silo w/ FGD, Inject FGD at 10 lbs/Mmacf (0.25 lbs/Mmbtu)*, EPRICON system OFF	* Full Load – 06:00-20:00 Official Request made for full load on Saturday, June 29 and Sunday, June 30
Parametric Week 4 (Carbon Injection –FGD)	June 30 – July 2	Day 1 – Inject FGD at 20 lbs/Mmacf (0.50 lbs/Mmbtu)*, EPRICON system OFF Day 2 – Inject FGD at 10 lbs/Mmacf (0.25 lbs/Mmbtu)* EPRICON system ON Day 3 – Inject FGD at 20 lbs/Mmacf (0.50 lbs/Mmbtu)* EPRICON system ON Day 4 –7 – Contingency	* Full Load – 06:00-20:00
Parametric Week 5	July 8-12	Day 1 – No Testing Day 2 – No Testing Day 3 – Load Silo w/ EPRI sorbent, Inject EPRI at 3 lbs/Mmacf (0.08 lbs/Mmbtu) * Day 4 – Inject EPRI at 10 lbs/Mmbtu (0.25 lbs/Mmbtu) Feed out sorbent Day 5 – Feed out sorbent	* Full Load – 06:00-20:00
Long Term Test (Carbon Injection – Norit FGD)	July 15 – 25	Day 1 – Load silo w/ FGD, Injection concentration TBD. Start Long Term Tests July 22, 23, 24 – OH (Operate at Full Load) *	* Full Load – July 22-24 (24 Hours a day)

[1] - *Low Load times are subject to change*

[3] - *Activity subject to MASS DEP Approval*

** - *Injection concentrations are subject to change depending on preliminary parametric test results*

FGD - Supplied from Norit Americas, Inc.
SAI - Supplied from Superior Adsorbents, Inc.
CC - Supplied from CarboChem
Donau - Supplied from Donau Carbon
EPRI - Supplied from EPRI

ADA Environmental Solutions, LLC

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memorandum

To:	Brian Wright, Ken Small, Sharon Sjostrom, Hg Project Team
From:	Travis Starns, Jean Bustard
CC:	Mike Durham
Date:	July 10, 2002
RE:	Parametric Test Results June 17 – July 2 and Long Term Test Plan

This memo provides a status and results update on the Brayton Point mercury tests. The original test plan called for parametric testing of FGD carbon at 1, 3 and 10 lbs/MMacf and alternate sorbents at 3 and 10 lbs/MMacf. These Injection concentrations were estimated based on results from the Pleasant Prairie tests. Based on the results presented in the earlier memo, injection test conditions were modified to also evaluate 20 lbs/MMacf with each sorbent. It was also of interest to evaluate FGD carbon at 7 and 15 lbs/MMacf.

Table 1 presents the test conditions for the 21 parametric tests conducted through July 2, 2002. This table also shows short-term mercury removal efficiencies across the new ESP. The data are graphically summarized in Figure 1. Observations include:

FGD Carbon

- Increased mercury removal when FGD carbon was tested at 1, 3, 10, and 20 lbs/MMacf.
- A second load of FGD carbon was delivered on Friday June 28 to conduct tests with EPRICON turned off (no SO_3 conditioning) and to repeat tests from the previous week to confirm results.

Other Sorbents

- Figure 2 also presents results from tests with three alternative sorbents (fourth sorbent will be tested July 10 and 11):
  - Superior Adsorbents Inc. (SAI), a bituminous activated carbon,
  - CarboChem (CC), a bituminous activated carbon imported from China, and
  - Donau Carbon Corporation (HOK), an activated lignite imported from Germany.
- These sorbents were tested at 3, 10, and 20 lbs/MMacf.
- At 3 lbs/MMacf SAI and CC had poor removal compared to FGD and HOK.
- At 10 lbs/MMacf SAI, CC, and HOK were all relatively close and comparable with each other. Mercury removal efficiencies ranged from 55 – 61% for all three sorbents.

- At 20 lbs/MMacf, both SAI and CC showed high removal with a range from 86 to 90%. While HOK showed a mercury removal of 75% at 20 lbs/MMacf.
- Two lance designs were tested with the SAI carbon. There are four ports at the injection location. With both designs, two lances are inserted into each port to distribute carbon to both the upper and lower sections of the 11 ft duct. Lance design 1 has a single large volume beveled opening oriented counter-current to flow 3 ft below the top of the duct and 4 ft above the bottom of the duct. The large volume beveled opening produces a wide-angle conical plume. Lance design 2 has 8 smaller openings drilled at 1 ft increments along the lance with carbon entering the duct from two sides of the lance normal to flow. The combined area of the smaller nozzles is almost equivalent to the single large volume opening of lance 1 The test showed that there was no difference in performance between the two lance designs, 59% versus 62% (we assume a 10% repeatability between tests). Lance design 2 was left in service for the remainder of the parametric tests.

Operational Issues

- After completing the testing at Pleasant Prairie and the first three weeks of testing at Brayton Point, powdered activated carbon (PAC) has shown to be very abrasive. After approximately one month's of service, the PAC wore a hole through a stainless steel section inside the distribution manifold. This caused an increase in pressure drop across the manifold and limited the feedrate capabilities of the injection system to around 20 lbs/Mmacf (~ 600 lbs/hr). For a permanent installation, one might consider ceramic lined piping or some other abrasive resistant material.
- Throughout the first 3 weeks of testing the boiler load signal from the plant has been quite noisy and fluctuated ± 20%. After troubleshooting all of the analog signals, it was found that the boiler load signal was being contaminated by an unshielded analog signal from the train 2 feeder. This problem has been corrected and this will allow the injection system to automatically adjust feedrate with changes in boiler load during the long term testing.
- Ash and Coal samples continue to be collected daily. Sampling frequency will increase during the long-term tests.

Long Term Test

A conference call with Brayton Point, NETL, EPA and EPRI was held to determine the long term test conditions. It was decided to inject PAC at two different injection concentrations. The long-term test will start July 15 at an injection concentration of 10 lbs/MMacf. We will test at this condition 24 hours a day until July 19. On July 18 and 19, TRC Environmental Corporation will perform the Ontario Hydro tests under this injection concentration. An additional set of Ontario Hydro measurements was added to confirm the high removal efficiencies. EPRI and DOE offered to pay for these tests. Once these tests are completed and the carbon content in the ash is determined to be under the limit as set by PG&E Brayton Point personnel, injection concentration will be increased to 20 lbs/MMacf. During testing, carbon content in the ash will be closely monitored. ADA-ES will coordinate with plant personnel to ensure carbon content in the ash stays below the maximum allowable limit. On July 22 and 23, TRC Environmental Corporation will conduct another set of Ontario Hydros. Testing will cease on July 25. The long term testing schedule can be seen in Table 2 below.

During the long term testing, ADA-ES requests that Unit 1 be held at full load between the hours of 06:00 – 20:00. However, on July 22 and 23, ADA-ES requests that Unit 1 be held at full load 24 hours a day. This will ensure a steady state condition while operating under the optimum conditions as determined from the parametric tests.

ADA-ES personnel will collect ash and coal samples daily during the long-term test. Samples will also be taken from the sorbent injection system with each load of PAC received.

Table 1: Preliminary Results From Brayton Point Parametric Tests
Removal Efficiency (RE) Measured Across the New ESP

Date	Duration (h)	Inj. Concen. (lbs/MMacf)	Sorbent	RE New ESP (%)	Lance Design
6/17/02	6	3	FGD	48	Single Nozzle
6/18/02	6	10	FGD	73	Single Nozzle
6/19/02	2.5	1	FGD	13	Single Nozzle
6/19/02	2.8	20	FGD	90	Single Nozzle
6/20/02	3	10	FGD	71	Single Nozzle
6/21/02	6	3	SAI	6	Single Nozzle
6/22/01	8	10	SAI	62	Single Nozzle
6/24/02		10	SAI	59	Multi Nozzle
6/25/02	6	3	CC	2	Multi Nozzle
6/26/02	6	10	CC	55	Multi Nozzle
6/26/02	3.5	20	CC	86	Multi Nozzle
6/27/02	3.25	3	HOK	18	Multi Nozzle
6/28/02	5.8	10	HOK	58	Multi Nozzle
6/28/02	2	20	HOK	75	Multi Nozzle
6/29/02	6	10	FGD *	71	Multi Nozzle
6/30/02	2.5	20	FGD *	93	Multi Nozzle
7/1/02	3.25	3	FGD	26	Multi Nozzle
7/1/02	2.5	10	FGD	62	Multi Nozzle
7/2/02	5.5	7	FGD	40	Multi Nozzle
7/2/02	3	15	FGD	77	Multi Nozzle

** These tests were conducted with the EPRICON system OFF*

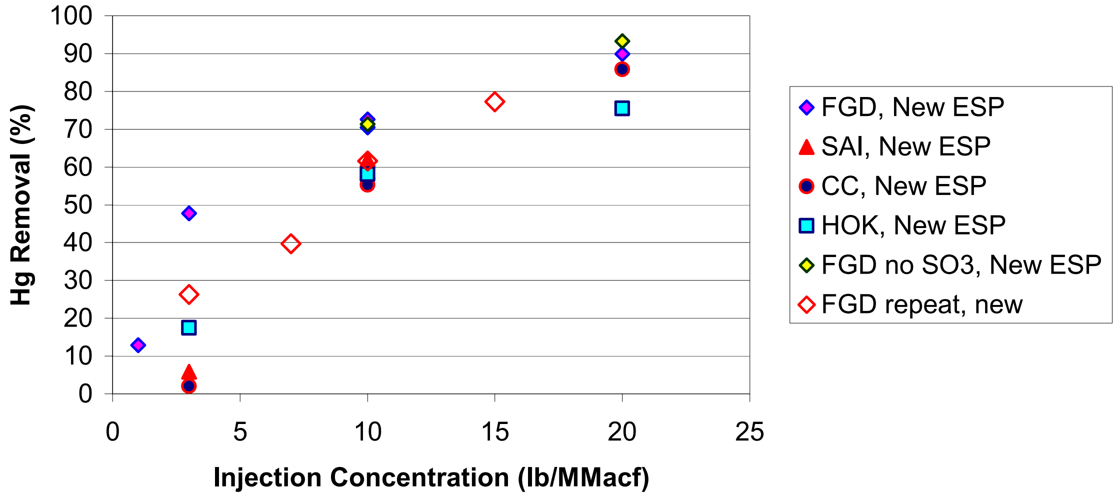
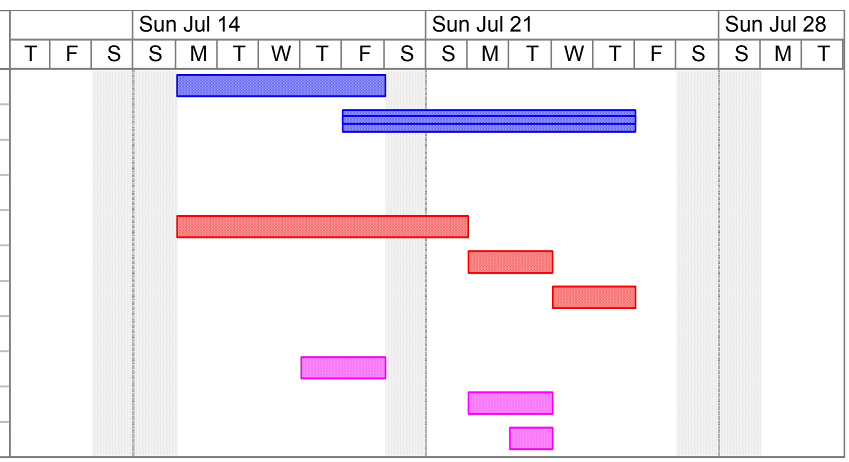


Figure 1. Mercury removal efficiencies measured across new ESP during Brayton Point parametric tests. All test conducted with EPRICON in service.

Table 2: Long Term testing schedule at Brayton Point

ID	Task Name
1	Long Term Test 1 - 10 lbs/MMacf
2	Long Term Test 2 - 20 lbs/MMacf
3	
4	
5	Unit 1 at Full Load ~ 245 MW (06:00 - 20:00)
6	Unit 1 at Full Load ~ 245 MW (24 hours/day)
7	Unit 1 at Full Load ~ 245 MW (06:00 - 20:00)
8	
9	Ontario Hydro Test - Series 1 (TRC)
10	Ontario Hydro Test - Series 2 (TRC)
11	Method 29's - Metals Test (TRC)



APPENDIX D

LONG-TERM TESTS

ADA Environmental Solutions, LLC

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memorandum

To:	Brian Wright, Ken Small, Sharon Sjostrom, Hg Project Team
From:	Travis Starns
CC:	Mike Durham
Date:	**July 29, 2002**
RE:	Brayton Point Long Term Test Completion

The long-term Performance Evaluation for PG&E NEG Brayton Point Station Unit 1 under the DOE/NETL Mercury Demonstration was completed on July 24, 2002. Two injection concentrations were tested for five days each at 10 lb/MMacf and 20 lb/MMacf. During this period, source sampling and other tests as listed in the project Test Plan were successfully conducted. Some observations on the test are included in this memo.

Process

As requested, Unit 1 was held at full load conditions (~ 245 MW) during each of the Ontario Hydro tests conducted for each of the injection concentrations (10 & 20 lbs/MMacf) tested. This contributed greatly to the successful completion of the testing schedule.

Unit 1 flyash was isolated from normal collection procedures and sent to a separate silo (silo #3) for disposal. With coordination from plant personnel, LOI levels in the ash collected from Unit 1 was monitored daily. LOI levels in the flyash averaged 9-10% during the long term test.

Sorbent was injected 24 hours/day with no interruptions. Feedrate calibration checks were made with feeder signals and silo weight measurements, both of which indicated that carbon injection was relatively steady at both injection rates. The sorbent injection system was placed under load following capabilities, in which sorbent feedrate was automatically calculated and adjusted with changes in Unit 1 load conditions.

Stack opacity was closely monitored with plant data collected from the PI data collection system. Opacity was also monitored with plant personnel (Control Room operators), and all indications showed no measurable increase in outlet emissions. Preliminary data analysis shows no detrimental impact to ESP performance during periods of sorbent injection into the second ESP.

Source Testing

A complete set of Ontario-Hydro sample runs were conducted by TRC Environmental Corporation for both of the injection concentrations. Sampling results were acceptable for all of these runs; final results are pending laboratory analysis.

Triplicate sets of EPA Method 29 Multi-Metals tests were conducted at the outlet of the second ESP.

Coal and Flyash Sampling

Flyash samples were collected daily from both ESPs front and back hoppers. One-liter containers were collected daily and 5-gallon samples collected on designated days during each test condition.

One-liter coal samples were collected daily from all four coal feeders. ADA-ES will ship these samples to the lab for ultimate and proximate analysis. A copy of the ash and coal sampling schedule can be found below in Table 2.

Mercury Monitors

Apogee Scientific sampled with their extractive monitors at four different locations on ½ of Unit 1 gas flow. A schematic representing these locations can be seen in figure 1 below. Data were collected continuously during all test periods. In particular, data were taken simultaneously with each of the Ontario Hydro sample runs. Preliminary results from the S-CEMs indicate 90-94% mercury removal at an injection concentration of 10 lbs/Mmacf and +96% removal at 20 lbs/MMacf.

Further Work

All recovered Ontario Hydro samples will be submitted to the analytical laboratory within the next week along with method blanks and prepared QA/QC spikes. Final results should be available within the 45 day holding period or no later than September 6, 2002.

Selected coal and ash samples will be forwarded to Dr. Senior at Reaction Engineering and then to the analytical subcontract laboratories.

Final results from the Mercury S-CEMs are pending review of data and calibrations by Apogee Scientific.

Figure 1: Hg S-CEM Locations

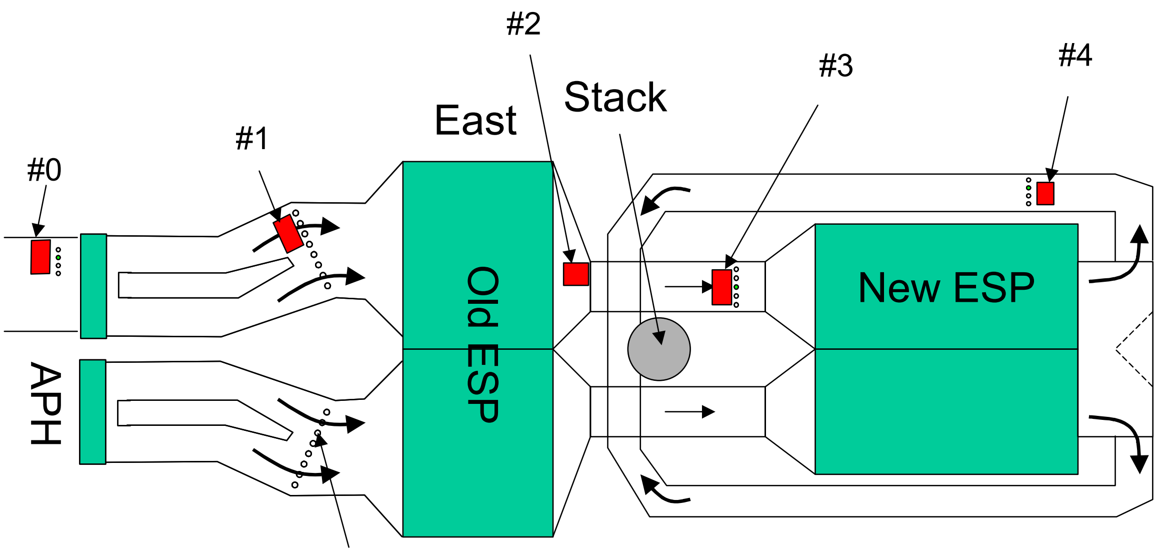

Table 2: Ash/Coal Sampling Schedule during Long Term Tests

A = 1 liter sample
B = 5 gallon sample

Date	Coal					Fly Ash														Ash Composite				
	Feeders					Old ESP Hoppers								New ESP Hoppers						Old ESP		New ESP		
	1-1	1-2	1-3	1-4	Composite	E1	E2	E3	E4	D1	D2	D3	D4	C1	C2	B1	B2	A1	A2	E-Row	D-Row	G-Row	B-Row	A-Row
15-Jul		A					A				A				A		A		A					
16-Jul		A					A				A				A		A		A					
17-Jul		A					A				A				A		A		A					
18-Jul		A					A				A				A		A		A					
19-Jul		A					A				A				A		A		A	1B		1B	1B	
20-Jul		A					A				A				A		A		A		1B	1B		
21-Jul		A					A				A				A		A		A			1B		
22-Jul	A	A	A	A		A	A	A	A	A	A	A	A	A	2A*	A	A	A	A	1B	1B	3B*	1B	1B
23-Jul	A	A	A	A		A	A	A	A	A	A	A	A	A	2A*	A	A	A	A	1B	1B	3B*	1B	1B
24-Jul																								
25-Jul																								

APPENDIX E

EMISSIONS TESTING REPORT

(Under Separate Cover)

APPENDIX F

ANALYSIS OF FLY ASH AND COAL

Date: December 12, 2002

From: Connie Senior

To: C. Jean Bustard

Re: Solid Sample Analysis from Long Term Testing at Brayton Point

---

Coal Analyses

Coal and ash samples were analyzed before the PAC injection was begun. Coals sampled during the baseline testing period are described in Table 1. The mercury contents are low, corresponding to a total gaseous mercury of ~5 μg/dnm^3. The chlorine contents of the coal are high (~1600 μg/g, dry basis). Table 2 gives the content of selected trace metals for the coal sample from 6/5/02.

Coals sampled during the long term testing period are described in Table 3. The mercury contents are slightly lower than the baseline, corresponding to total gaseous mercury of 6-7 μg/dnm^3. The chlorine contents of the coal are high (1300-1600 μg/g, dry basis), although generally 10-25% lower than the baseline.

Table 1. Analyses of coal samples from baseline testing

ADA Sample	BRP00272	BRP00273	BRP00274
MTI Sample	**02-146**	**02-147**	**02-145**
Date/Time	**6/5/02**	**6/6/02**	**6/7/02**
ULTIMATE ANALYSIS (As Received):			
Carbon	71.96	72.21	72.34
Hydrogen	4.53	4.39	4.57
Oxygen	5.32	5.68	5.18
Nitrogen	1.39	1.39	1.44
Sulfur	0.61	0.63	0.60
Ash	11.80	10.82	11.63
Moisture	4.40	4.88	4.25
Total	100.00	100.00	100.01
Hg, µg/g	0.042	0.046	0.053
Cl, µg/g	1,702	1,598	1,599
HHV, Btu/lb	12,775	12,793	12,812
SO_2, lb/MBtu	0.96	0.98	0.94
Ash, lb/MBtu	9.23	8.46	9.08
Hg, lb/TBtu	3.29	3.58	4.12
Hg, µg/dnm^3 (3%O_2)	4.46	4.89	5.56
PROXIMATE ANALYSIS (As Received):			
Fixed Carbon	53.05	53.89	53.65
Volatile matter	30.75	30.41	30.47
Ash	11.8	10.82	11.63
Moisture	4.4	4.88	4.25
Total	100	100	100

ADA Sample	BRP00272	BRP00273	BRP00274
MTI Sample	**02-146**	**02-147**	**02-145**
Date/Time	**6/5/02**	**6/6/02**	**6/7/02**
ULTIMATE ANALYSIS (Dry):			
Carbon	75.27	75.91	75.55
Hydrogen	4.74	4.62	4.77
Oxygen	5.56	5.97	5.41
Nitrogen	1.45	1.46	1.5
Sulfur	0.64	0.66	0.63
Ash	12.34	11.38	12.15
Moisture			
Total	100	100	100.01
Hg, µg/g	0.044	0.0482	0.0551
Cl, µg/g	1780	1680	1670
HHV, Btu/lb	13,363	13,449	13,381
PROXIMATE ANALYSIS (Dry):			
Fixed Carbon	55.49	56.65	56.03
Volatile matter	32.17	31.97	31.82
Ash	12.34	11.38	12.15
Moisture			
Total	100	100	100

Table 2. Metals content of coal from baseline testing

ADA-ES #	MTI #	As, µg/g	Cd, µg/g	Pb, µg/g	Se, µg/g
BRP00272	02-146	5.68	0.055	8.90	3.0

Table 3. Analyses of coal samples from long term testing

ADA Sample	BRP00199	BRP00209	BRP000275	BRP000276	ADA Sample	BRP00199	BRP00209	BRP000275	BRP000276
MTI Sample	**02-141**	**02-142**	**02-143**	**02-144**	**MTI Sample**	**02-141**	**02-142**	**02-143**	**02-144**
Date/Time	**7/17/02**	**7/18/02**	**7/22/02**	**7/23/02**	**Date/Time**	**7/17/02**	**7/18/02**	**7/22/02**	**7/23/02**
ULTIMATE ANALYSIS (As Received):					**ULTIMATE ANALYSIS (Dry):**				
Carbon	71.69	73.27	72.78	71.34	Carbon	75.07	76.56	76.72	74.83
Hydrogen	4.45	4.73	4.56	4.38	Hydrogen	4.66	4.94	4.81	4.59
Oxygen	5.95	5.87	6.19	4.99	Oxygen	6.23	6.13	6.53	5.23
Nitrogen	1.36	1.35	1.38	1.34	Nitrogen	1.42	1.41	1.45	1.41
Sulfur	0.76	0.68	0.69	0.60	Sulfur	0.8	0.71	0.73	0.63
Ash	11.29	9.80	9.25	12.69	Ash	11.82	10.24	9.75	13.31
Moisture	4.50	4.30	5.14	4.67	Moisture				
Hg, µg/g	0.072	0.075	0.054	0.058	Hg, µg/g	0.0751	0.0781	0.0574	0.0604
Cl, µg/g	1499.35	1502.49	1603.13	1296.49	Cl, µg/g	1570	1570	1690	1360
HHV, Btu/lb	12,672	12,947	12,904	12,598	HHV	13,269	13,529	13,603	13,215
SO_2, lb/MBtu	1.21	1.05	1.07	0.95					
Ash, lb/MBtu	8.91	7.57	7.17	10.07					
Hg, lb/TBtu	5.66	5.77	4.22	4.57					
Hg, µg/dnm^3 (3%O_2)	7.68	7.76	5.74	6.18					
PROXIMATE ANALYSIS (As Received):					**PROXIMATE ANALYSIS (Dry):**				
Fixed Carbon	53.33	53.48	54.72	52.82	Fixed Carbon	49.54	55.88	49.25	55.41
Volatile matter	30.88	32.42	30.89	29.82	Volatile matter	43.14	33.88	43.6	31.28
Ash	11.29	9.8	9.25	12.69	Ash	7.32	10.24	7.15	13.31
Moisture	4.5	4.3	5.14	4.67	Moisture				

Ash Analyses

Ash samples were taken from both the first (Old) ESP and the second (New) ESP. Contents of mercury, chlorine and LOI are given in Table 4. There are not large differences between the samples from the two ESPs. Ash from the New ESP has somewhat higher Hg, Cl and LOI, but this does not represent a consistent difference between the Old and New ESPs. However, it is not possible to conclude that there are (or are not) differences between the ash in these two ESPs without more samples.

Table 4. Analyses of ash samples from baseline testing

Sample ID	MTI ID	Date	Location	Hg, µg/g	Cl, µg/g	LOI, %
BRP00062	02-152	6/6/2002	E-2 (Old ESP)	0.205	88.7	4.26
BRP00066	02-167	6/6/2002	D-2 (Old ESP)	0.321	110	4.44
BRP00086	02-154	6/7/2002	E-2 (Old ESP)	0.241	91.5	3.09
BRP00070	02-153	6/6/2002	C-2 (New ESP)	0.526	134	5.46
BRP00072	02-168	6/6/2002	B-1 (New ESP)	0.231	84.8	3.14
BRP00090	02-155	6/7/2002	C-2 (New ESP)	0.529	156	5.73

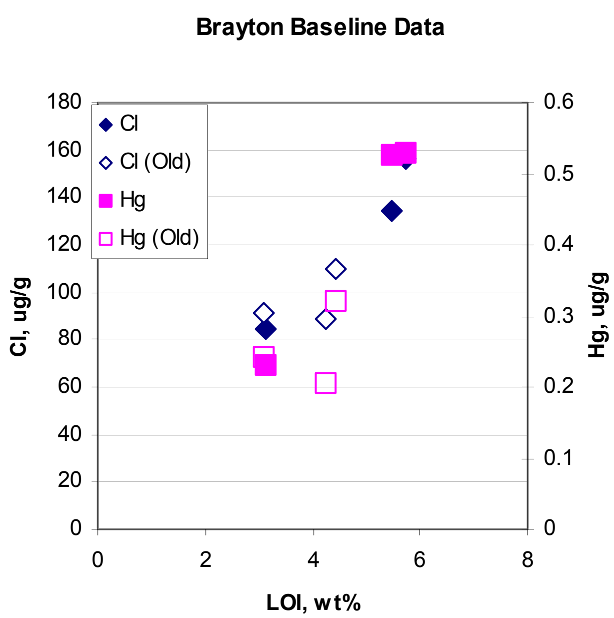

Figure 1. Hg and Cl in ash as a function of LOI (Brayton baseline tests).

The amount of LOI in the ash appears to correlate with the mercury or chlorine contents of the ash for the New ESP ash; the correlation does not appear as strong for the Old ESP ash (Figure 1), but it is difficult to draw conclusions from so few samples. Unburned carbon in the ash may adsorb both mercury and chlorine, although this does not say anything about the nature of the adsorbed species or whether chlorine affects mercury adsorption on the ash.

There is also a possibility that the alkali and alkaline earth elements in the ash are responsible for adsorbing chlorine. In order to look at this, we analyzed several ash samples (three Old ESP and one New ESP, with carbon injection) for ash composition. Table 5 gives the analysis of these ash samples; Table 6 shows the total alkali and alkaline earth oxides contrasted with the LOI, mercury and chlorine contents.

Table 5. Ash Analysis (SO_3-free basis)

Oxide	MTI 02-150 (BRP000236)	MTI 02-151 (BRP000238)	MTI 02-152 (BRP000062)	MTI 02-167 (BRP 000066)
Al_2O_3	25.63	24.61	22.56	23.38
BaO	0.10	0.09	0.09	0.11
CaO	2.50	1.40	8.07	8.95
Fe_2O_3	3.35	2.81	5.11	5.82
MgO	1.03	0.75	1.18	1.33
MnO_2	0.04	0.03	0.05	0.05
P_2O_5	0.15	0.07	0.19	0.23
K_2O	2.33	1.88	2.07	2.11
SiO_2	62.22	66.24	58.35	55.54
Na_2O	0.86	0.44	0.78	0.84
SrO	0.09	0.07	0.12	0.13
TiO_2	1.70	1.60	1.43	1.50

Table 6. Total alkali and alkaline earth oxides from ash analysis (SO_3-free basis)

Sample ID	MTI ID	Date	Location	PAC, lb/MMacf	Hg, µg/g	Cl, µg/g	LOI, %	Ca+Mg+Na+K (wt% oxides)
BRP00062	02-152	6/6/2002	E-2 (Old ESP)	0	0.205	88.7	4.26	12.10
BRP00066	02-167	6/6/2002	D-2 (Old ESP)	0	0.321	110	4.44	13.23
BRP00236	02-150	7/22/2002	C-1 (New ESP)	20	0.595	1100	16.8	6.72
BRP00238	02-151	7/22/2002	E-4 (Old ESP)	20	0.158	14.8	5.05	4.47

There may be a relationship between alkali/alkaline earth content and the chlorine content of the ash from the Old ESP (Figure 2), although it is hard to draw firm conclusions from only three samples.

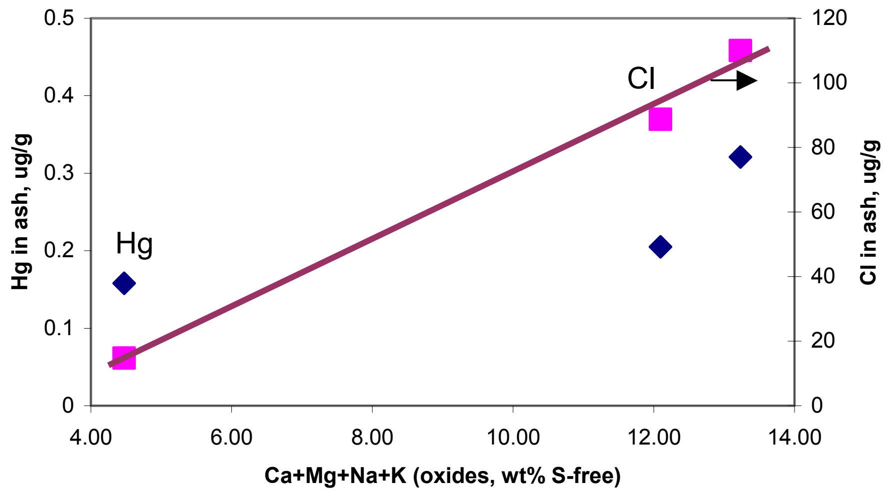

Figure 2. Mercury and chlorine on ash from Old ESP as a function of alkali and alkaline earth content of ash.

The mercury and chlorine contents of the ash, along with the LOI, are given in Tables 7 and 8 for the Old and New ESPs, respectively. Since PAC was injected after the Old ESP, there should not be any impact of PAC on the ash properties. Neither the LOI nor the mercury content of the Old ESP ash differ significantly between the baseline and long term samples. The chlorine in the baseline ash is significantly higher than in the long-term ash. However, coal chlorine was only 10-25% higher for the long term tests as compared to the baseline tests. Perhaps there were other operational changes that affected chlorine.

The New ESP ash samples from the long-term tests contain activated carbon. As shown in Figure 3, there is a predictable increase in mercury with LOI. The chlorine content of the ash also increases with increasing LOI (that is, with PAC injection).

Table 7. Composition of ash from Old ESP

Sample ID	MTI ID	Date	Location	PAC, lb/MMacf	Hg, µg/g	Cl, µg/g	LOI, %
BRP00062	02-152	6/6/2002	E-2 (Old ESP)	0	0.205	88.7	4.26
BRP00066	02-167	6/6/2002	D-2 (Old ESP)	0	0.321	110	4.44
BRP00086	02-154	6/7/2002	E-2 (Old ESP)	0	0.241	91.5	3.09
BRP00207	02-159	7/18/2002	D-3 (Old ESP)	10	0.395	19	5.55
BRP00197	02-156	7/17/2002	E-3 (Old ESP)	10	0.151	17.9	4.73
BRP00208	02-149	7/18/2002	E-3 (Old ESP)	10	0.184	16.5	5.65
BRP00214	02-161	7/19/2002	E-3 (Old ESP)	10	0.213	20.6	6.15
BRP00232	02-162	7/22/2002	D-Row (Old ESP)	20	0.332	30.5	8.88
BRP00254	02-165	7/23/2002	E-3 (Old ESP)	20	0.265	50.4	3.98
BRP00238	02-151	7/22/2002	E-4 (Old ESP)	20	0.158	14.8	5.05

Table 8. Composition of ash from New ESP

Sample ID	MTI ID	Date	Location	PAC, lb/MMacf	Hg, µg/g	Cl, µg/g	LOI, %
BRP00070	02-153	6/6/2002	C-2 (New ESP)	0	0.526	134	5.46
BRP00072	02-168	6/6/2002	B-1 (New ESP)	0	0.231	84.8	3.14
BRP00090	02-155	6/7/2002	C-2 (New ESP)	0	0.529	156	5.73
BRP00204	02-158	7/18/2002	B-Row (New ESP)	10	1.37	1300	19.9
BRP00202	02-157	7/17/2002	C-2 (New ESP)	10	0.53	321	8.49
BRP00213	02-160	7/19/2002	C-2 (New ESP)	10	0.76	725	11.2
BRP00205	02-148	7/18/2002	C-Row (New ESP)	10	0.526	450	12
BRP00233	02-163	7/22/2002	A-Row (New ESP)	20	0.748	1700	27.8
BRP00234	02-234	7/22/2002	B-1 (New ESP)	20	0.666	2000	26.6
BRP00236	02-150	7/22/2002	C-1 (New ESP)	20	0.595	1100	16.8
BRP00262	02-166	7/23/2002	C-1 (New ESP)	20	0.409	975	12.2

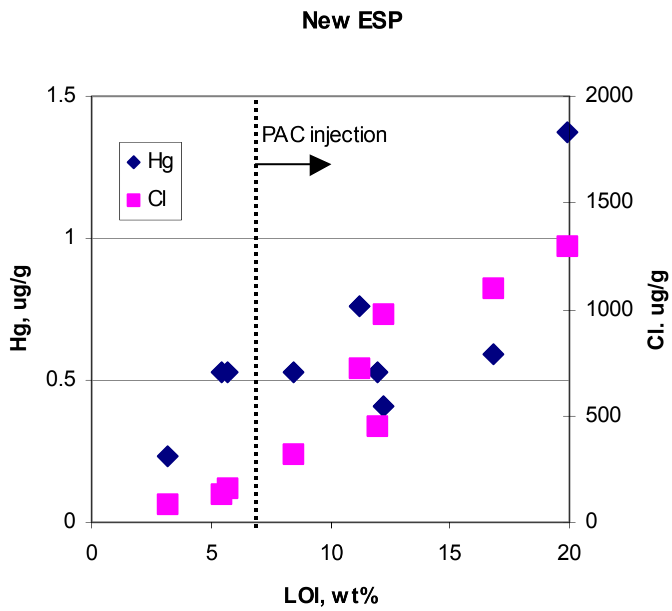

Figure 3. Mercury and chlorine as a function of LOI for New ESP ash samples (with and without sorbent injection).

Table 9 gives the results of TCLP and SGLP procedures carried out on baseline and long-term ash samples. Detectable amounts of mercury were leached from most samples, in the range of 0.01 to 0.07 µg/L (or ppbw). Note that the primary drinking water standard specifies 2 ppbw for Hg via TCLP analysis. Thus, the amounts of mercury leached from these samples are about 100 times lower than the primary drinking water standard. There is no clear difference between the Old ESP and New ESP samples as far as leaching of mercury is concerned, nor is there a difference between the baseline and long-term New ESP samples. Thus, PAC injection does not seem to have increased the amount of mercury leached from the ash.

Table 9. Leaching results for Brayton Point ash

ADA-ES #	MTI Sample #	Sample name	TCLP ug Hg/L	SGLP ug Hg/L
BRP00062	02-152	6/6, E-2, Old ESP	0.02	0.05
BRP00070	02-153	6/6, C-2, New ESP	< 0.010	0.01
BRP00205	02-148	7/18, C-row, New ESP	0.07	0.03
BRP00208	02-149	7/18, E-3, Old ESP	0.03	0.01
BRP00236	02-150	7/22, C-1, New ESP	< 0.010	0.01
BRP00238	02-151	7/22, E-4, Old ESP	0.02	0.02

The ash was also analyzed for four trace metals: As, Cd, Pb, and Se (Table 10). In general the New ESP ash has higher concentrations of these trace elements in the ash than the Old ESP ash by about a factor of two or three. Since the LOI of the ash is fairly uniform between the two ESPs, the differences in trace metal content are probably due to differences in the size of ash collected by the two ESPs. The concentration of these trace metals, which are semi-volatile in the combustion process, is not generally uniform as a function of ash particle size.

Table 10. Trace metal analysis of Brayton Point ash

Sample ID	MTI ID	Date	Location	PAC, lb/MMacf	As, ug/g	Cd, ug/g	Pb, ug/g	Se, ug/g
BRP00062	02-152	6/6/2002	E-2 (Old ESP)	0	33	0.3	68.4	11
BRP00086	02-154	6/7/2002	E-2 (Old ESP)	0	36	0.6	77.7	9.9
BRP00208	02-149	7/18/2002	E-3 (Old ESP)	10	24	0.26	65.1	10
BRP00238	02-151	7/22/2002	E-4 (Old ESP)	20	19	0.27	64.4	14
BRP00070	02-153	6/6/2002	C-2 (New ESP)	0	82.3	0.81	132	34
BRP00090	02-155	6/7/2002	C-2 (New ESP)	0	90.1	0.8	139	38
BRP00205	02-148	7/18/2002	C-Row (New ESP)	10	36.2	0.47	91.7	43.8
BRP00236	02-150	7/22/2002	C-1 (New ESP)	20	31	0.42	92.5	94.2

PAC injection does not have a large effect on the concentration of As, Cd, or Pb in the ash. In fact, the concentration of these metals in the New ESP samples decreases when PAC is injected; this is a dilution effect.

In contrast, the concentration of Se increases in the ash after PAC is injected. Figures 4 through 6 illustrate this by contrasting the concentration of trace metals *normalized to a carbon-free basis* as a function of PAC injection rate. For As, Cd, and Pb, the carbon-free concentration decreases slightly with PAC injection because the ash content of the PAC has not been taken into account. However, Se increases markedly in the New ESP ash when PAC is injected. This is probably because there is Se present in the gas-phase at the ESP and it is adsorbed on the activated carbon. Thus, at Brayton Point, it appears that the activated carbon adsorbs Se as well as Hg.

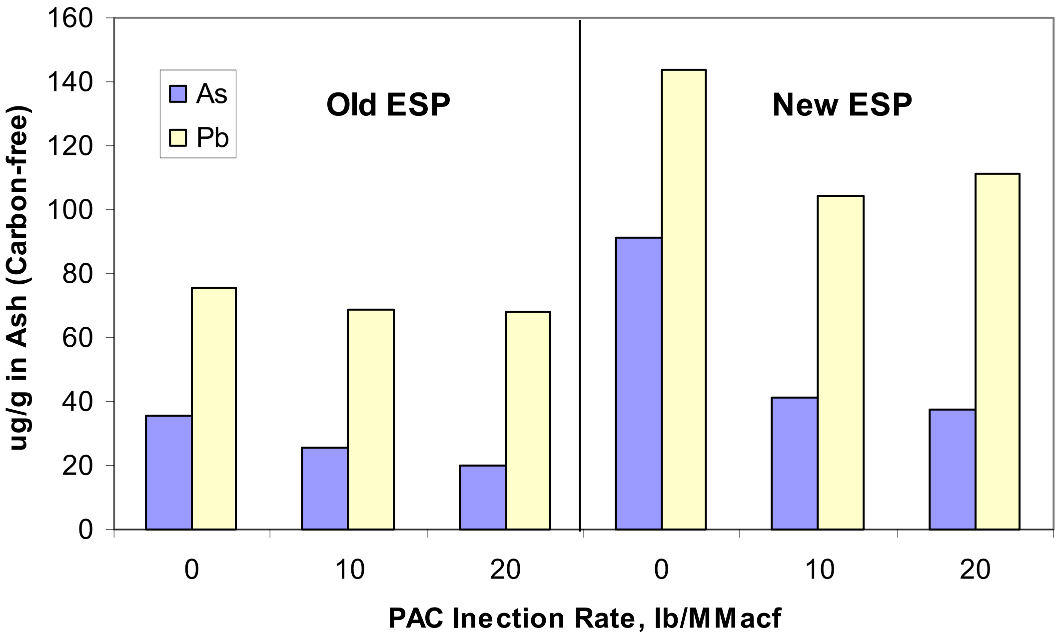

Figure 4. Concentration of As and Pb in Brayton Point ash (normalized to a carbon-free basis).

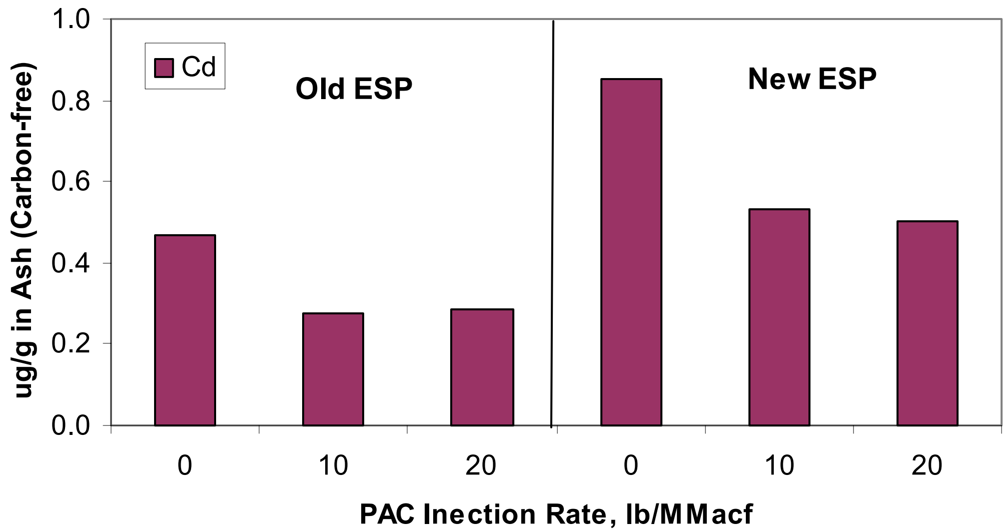

Figure 5 Concentration of Cd in Brayton Point ash (normalized to a carbon-free basis).

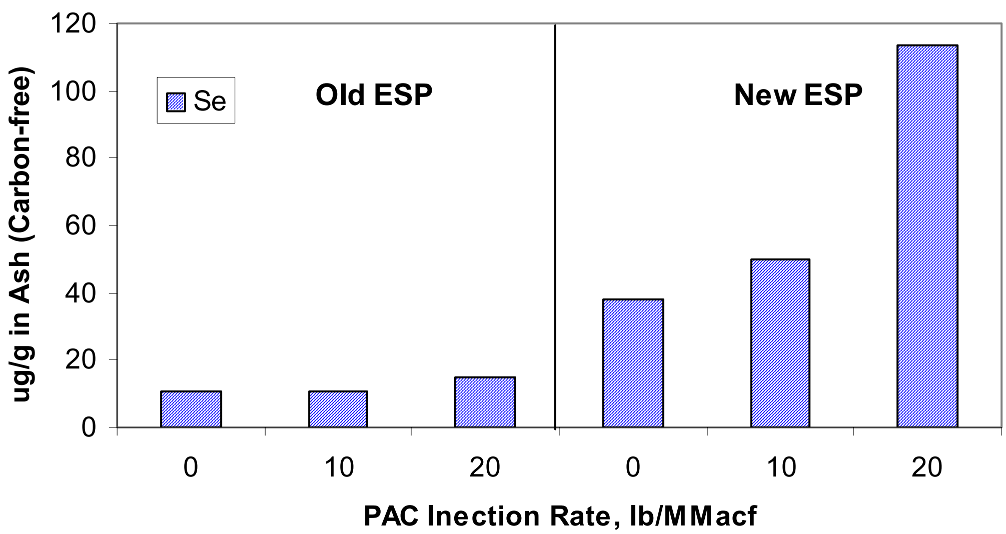

Figure 6 Concentration of Se in Brayton Point ash (normalized to a carbon-free

APPENDIX G

ECONOMIC ANALYSIS

NORIT COST QUOTE AND EQUIPMENT LISTS

DESIGN DRAWINGS

ECONOMICS

COST FACTORS

NORIT AMERICAS INC.

ADA.ES

BRAYTON POINT STATION
PG&E NATIONAL ENERGY GROUPS

PAC INJECTION SYSTEM – EQUIPMENT LIST & BUDGET PRICING
for 600 #/hr Feedrate

1 each Powdered Activated Carbon Storage Silo, 14 ft. dia. including:
- 216,000 pound PAC Storage Capacity
- 77 Feet, Eave Height
- Caged Ladder Access and Rest Platform to Roof Mounted Equipment
- Roof Perimeter Handrail
- Two each Windowed Access Doors into Skirted Area
- Galvanized Anchor Bolts
- 4" Schedule 40 Fill Line Pipe and Supports
- Combination Vacuum/Pressure Relief Valve and Manway
- Freight for Delivery

1 each Silo Vent Filters for Truck Unloading of PAC
3 each Silo Point Level Switches: High, Low and Low-Low
1 each Silo Level Transmitter
4 each BLH Load Cells to measure Silo Storage Weight
1 each Precast Concrete Power and Control Building Including:
- 3'-0" X 6'-8" Windowed Access Door – 2 each
- Motor Control Center - 460 VAC
- Control Panel
- HVAC
- Lighting
- All Equipment Mounted and Wired
- Freight for Delivery

1 each Feeder Control Panels including:
- Feeder Speed Controllers
- PanelView 1000 Color Operator Interface
- Allen Bradley SLC 504 PLC
- Load Cell Indicator/Transmitter
- Emergency Stop Pushbutton
- Feeder HOA Control Switches

3 each Skid Mounted Feeder systems, including:
- Painted Tube Steel Support Frame
- Stainless Steel Feeder and Storage Hopper
- Hopper Level Switches: High and Low
- Pressure Switch to Verify Eductor Operation
- Solids Conveying Eductor
- Freight for Delivery

3 each Motive Air Blowers
3 each Silo Discharge Knife Gate Valves
3 each Rotary Valves for Filling Feeder Hoppers
3 each Expansion Joints to connect Rotary Valves to Feeder Hoppers
1 each Truck Unloading Control Panels
Air Fluidizing Headers, Nozzles, Valves, Tubing and Gauges
Silo Interior Lights and Switch
Silo Deck Light and Switch
Operations and Maintenance Manuals – 5 sets
Field Engr. Support for Installation/Startup, 2 weeks: Included

SPARE PARTS INCLUDED:

- 0 each Eductor
- 0 each Point Level Switch
- 0 each Silo Fluidizing Air Solenoid Valve
- 0 each Set of Vent Filter Bags
- 0 each Feeder Speed Controller
- 0 each Feeder Drive Motor Speed Pick-up
- 0 each Feeder Drive Motor
- 0 each Volumetric Feeder Auger
- 0 each Volumetric Feeder Gasket
- 0 each Blower Replacement Inlet Air Filters

PRICING ESTIMATE:
Engineering, Material and Equipment, Delivered: $354,000
Note: Pricing does not include foundation design, injection piping or installation.

Figure 1. Process and Instrumentation Diagram ACI System – Sheet 1 of 2

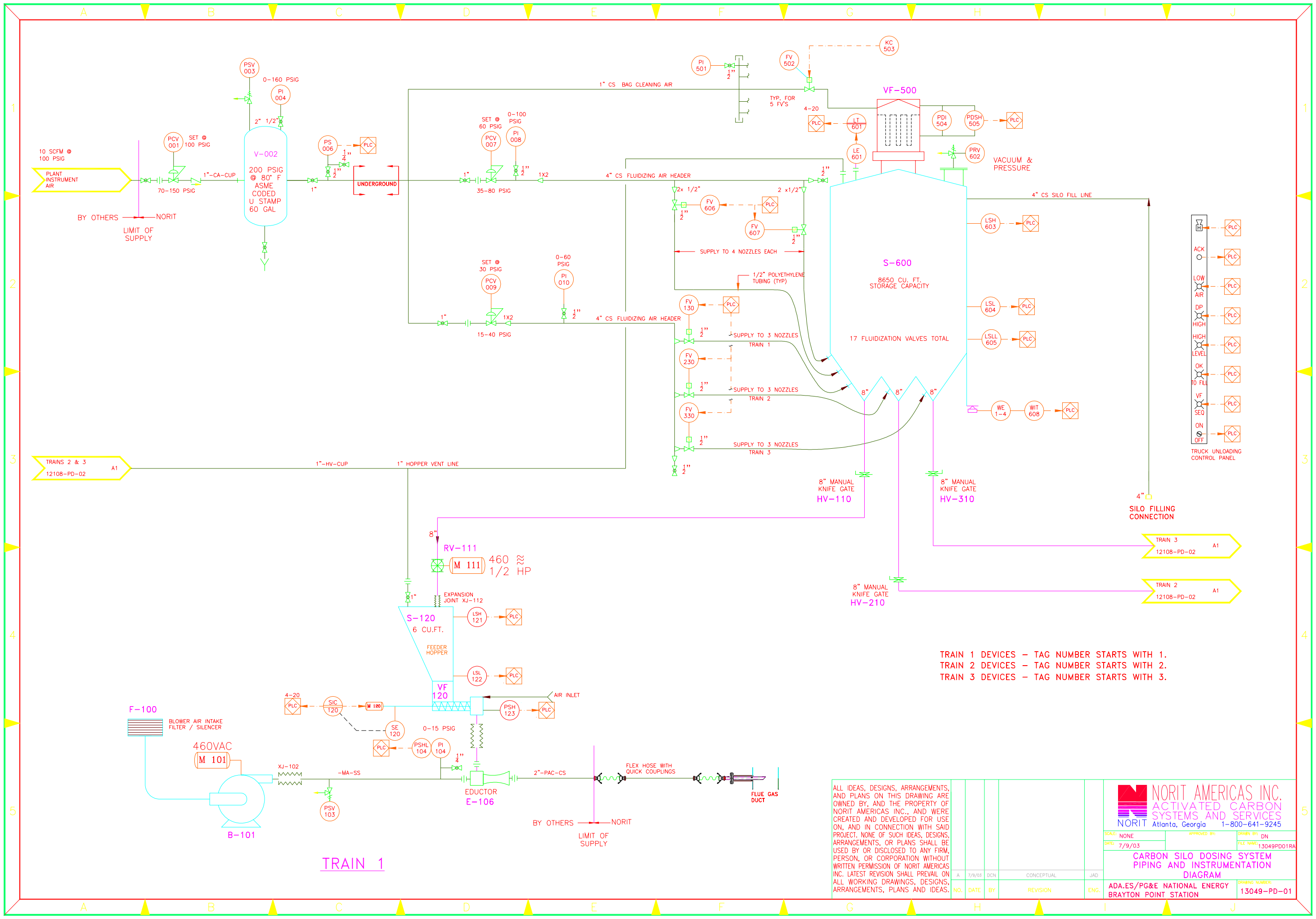

Figure 2. Process and Instrumentation Diagram ACI System – Sheet 2 of 2

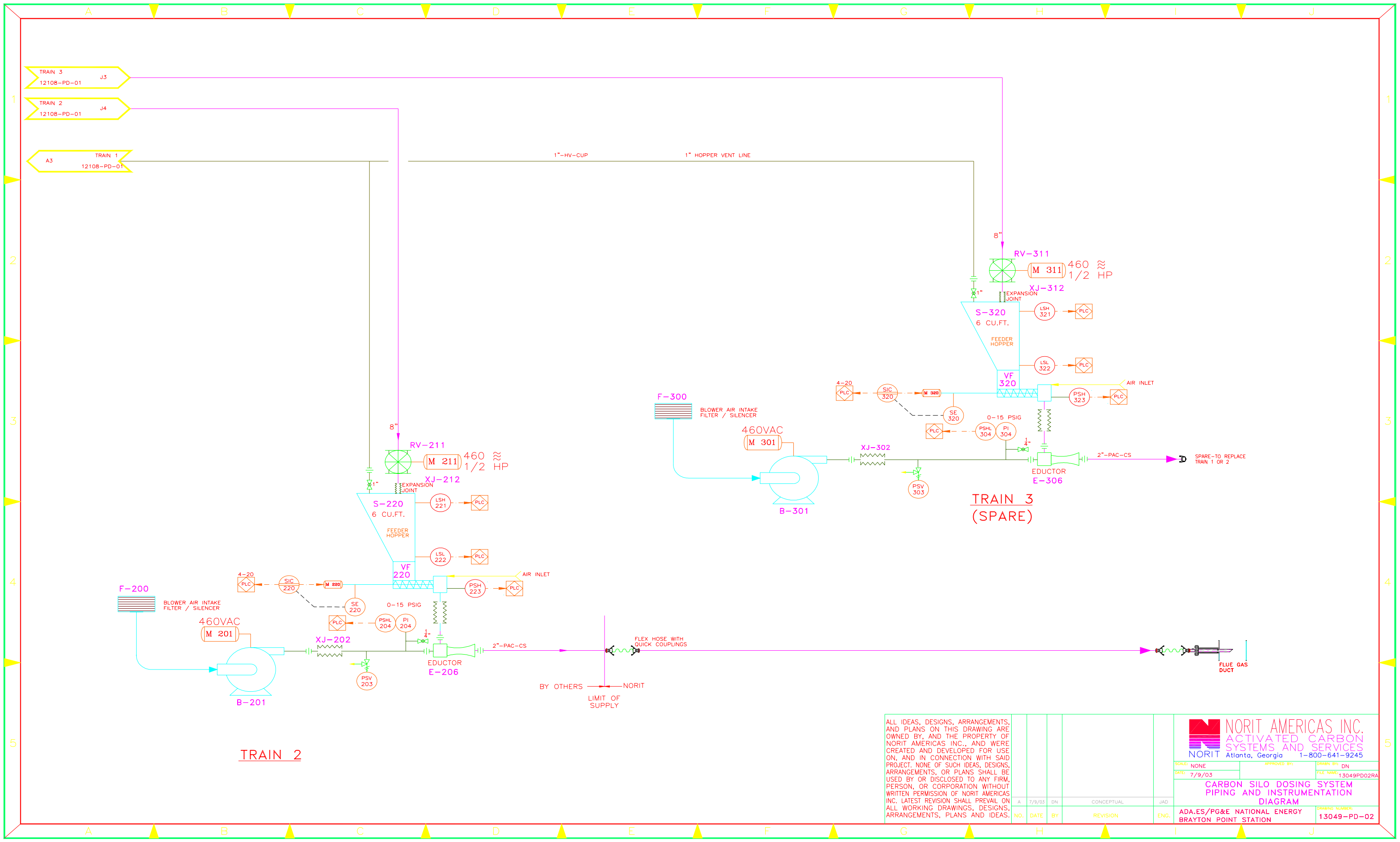

Figure 3. Under Silo Skirt Area Plan View

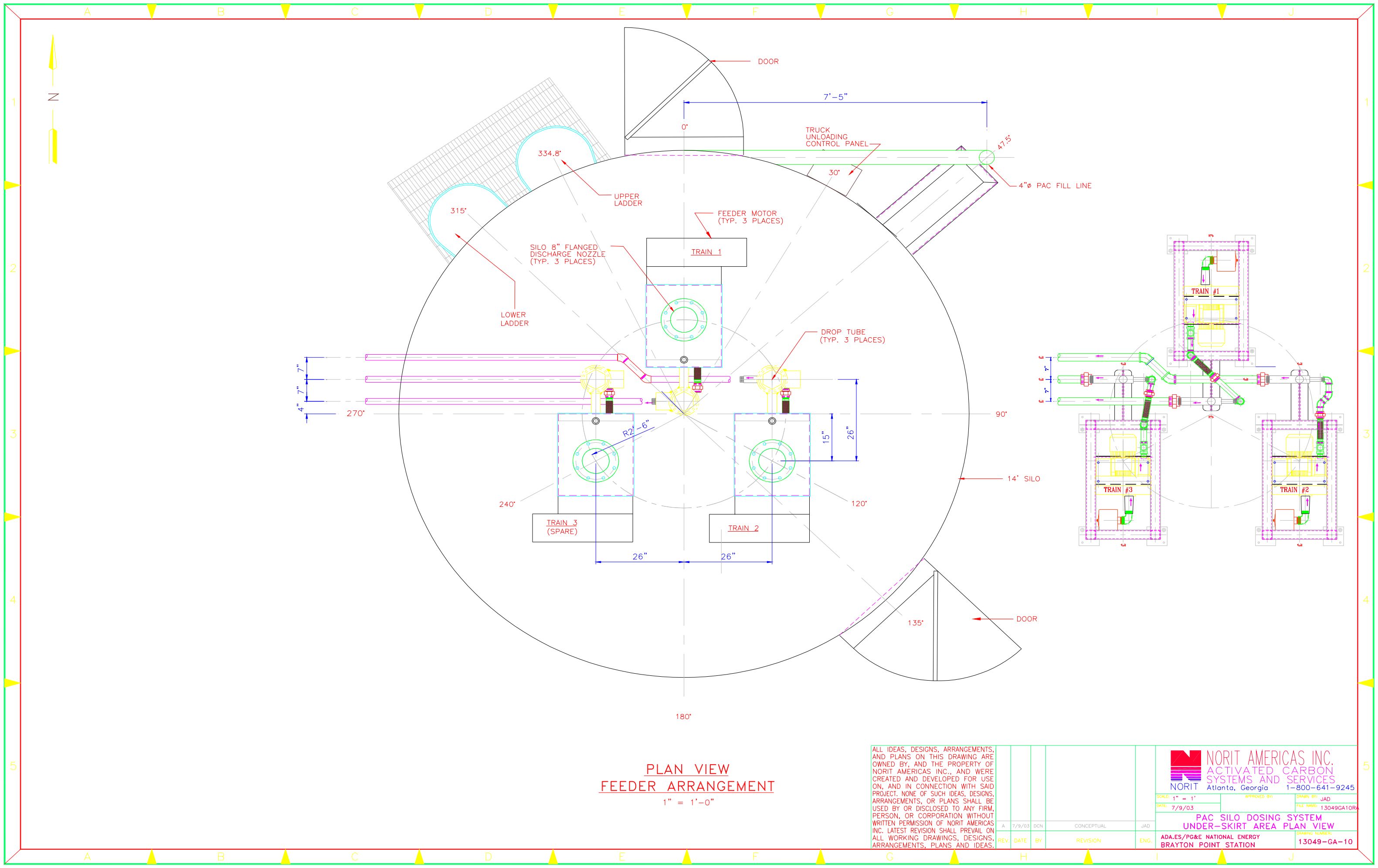

Figure 4. Control Building Plan View

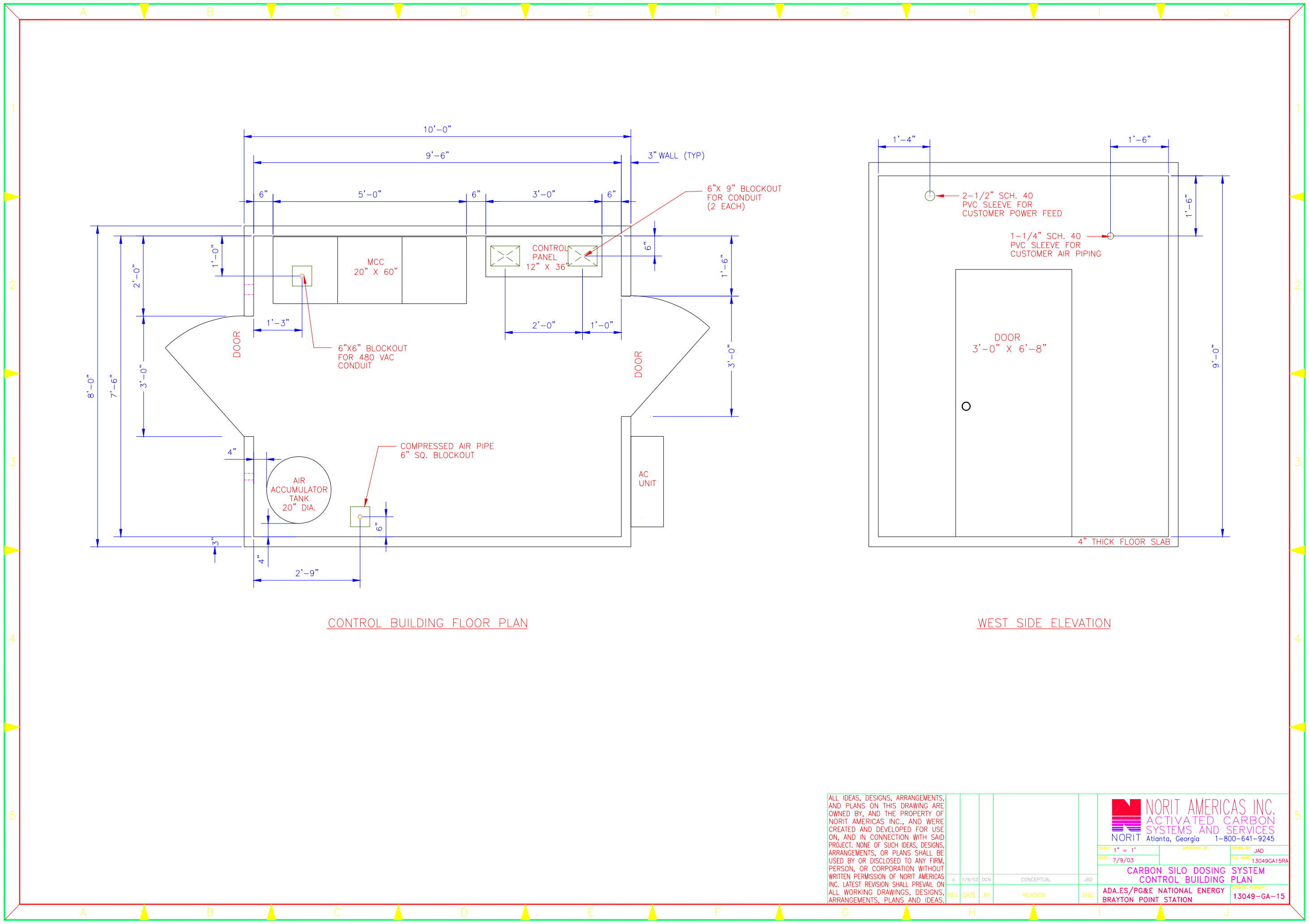

Table 1. Summary of Brayton Point Economics

		ESP Case
Capital Costs		
ACI Storage and Injection System	$	$407,100
Piping, Manifolds & Lances	$	$40,000
Foundations and Steel (installed)	$	$58,500
Electrical Supply Upgrades	$	$20,000
Misc Utilities, Lighting		$10,000
Controls Integration	$	$20,000
Subtotal		$555,600
Taxes	$	$33,336
Freight	$	*incl*
Purchased Equipment Cost Subtotal	$	$588,936
Installation of Process Equipment	$	$79,200
Total Direct Cost	$	$668,136
Indirects		
General Facilities	10%	$66,814
Engineering Fees	10%	$66,814
Project Contingency	15%	$100,220
Process Contingency	5%	$33,407
Total Plant Cost (TPC)	$	$935,390
Allow. for Funds During Constr. (AFDC)	$	$0
Total Plant Investment (TPI)	$	$935,390
Preproduction Costs	$	$0
Inventory Capital	$	$0
Total Capital Requirement (TCR)	$	**$935,390**
	$/kW	$3.74
Variable O&M and Costs		
Cost Basis (Year)		2003
'Sorbent Injection Rate (lbs/hr)		600
Sorbent Costs		$2,233,800
Waste Disposal Costs		$1,306,800
Power Consumption	kW	60
Power Cost ($0.05/kW)		$22,338
Operating Labor (1 hours/day, $45/hr))		$16,425
Maintenance Costs		$22,355
Periodic Replacement Items		$10,000
COHPAC Bag replacement penalty*		
Total	$	$3,611,778
$/kW	$/kW	$14.45
mills/kWhr	mills/kW-hr	1.94
		1.94

Economic Factors

Net Generating Capacity	MW	250
Annual Capacity Factor	%	85%
Power costs	$/kw	$0.05
Operating Labor Rate	$/hr	$45
Cost Basis - Year Dollars	Year	2003
Capital Esc During Construction	%	1.5%
Construction Years		0.5
Annual Inflation	%	2.5%
Discount Rate, % (MAR) =	%	9.2%
AFUDC Rate	%	10.8%
First Year Fixed Charge Rate, Current$	%	22.3%
First Year Fixed Charge Rate, Const$	%	15.7%
Lev Fixed Charge Rate, Current$ (FCR) =	%	16.9%
Lev Fixed Charge Rate, Const$ (FCR) =	%	11.7%
Service Life (years) =	Years	20
Escalation Rates :		
Consumables (O & M) =	%	3.0%
Fuel =	%	5.0%
Power =	%	3.0%
		Current$ Basis
P/A Factor		9.00
A/P Factor		0.11
P/AE Factors		
'Consumables (O&M)		11.45
'Power		11.45
Levelizing Factors		
'Consumables (O&M)		1.27
'Power		1.27

First Year Costs

		ESP Case
Fixed Costs		$146,856
Variable O&M		$3,611,778
Total First Year Costs	$	$3,758,634
$/kw	$/kW	$15.03
	mills/kW-hr	2.02

20 yr Annual Levelized Costs

		Current$ Basis
Fixed Costs		$109,441
Operating Costs		
'Reagent		$2,842,378
'Waste Disposal		$1,662,825
'Power		$28,424
'Labor		$20,900
'Maint		$28,445
'Spare Parts		$12,724
Total Annual 20 yr Levelized Costs	$/year	$4,705,137
$/kW	$/kW	$18.82
	mills/kW-hr	2.53